System Integration of Distributed Power For Complete Building Systems

Presented by
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System Integration of Distributed Power For Complete Building Systems

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NREL Technical Monitor: Holly Thomas

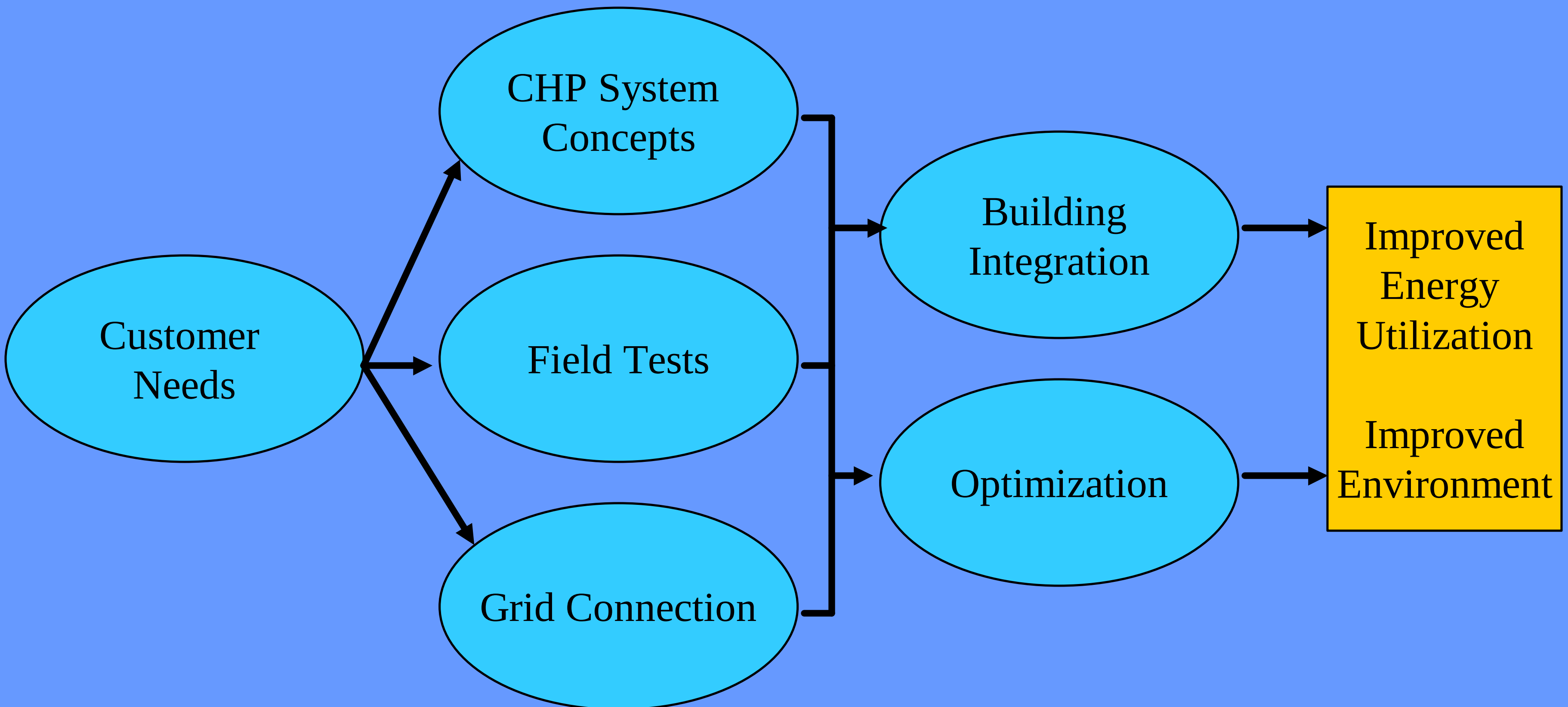
Research Team Members:
Principal Investigator: Dr. Robert Kramer, NiSource Energy Technologies (NET), Merrillville, IN

Sub-tier Principal Investigator : Dr. Rahmat Shoureshi, Colorado School of Mines (CSM), Golden, CO

Project Objectives

- Three-phase, multi-year research and development effort to advance distributed power development, deployment, and integration
- Develop, test, and optimize several (electric/natural gas/ renewable energy) stand-alone distributed power systems
- Develop and initiate laboratory and field tests, methodologies, controls (including command, communications, monitoring, efficiency, and heat rate)
- Fully document, publish, and otherwise disseminate (through regional/national speeches, reports, and conferences) non-proprietary results and conclusions for maximum national replicability

NET Approach



NiSource Operating Territory

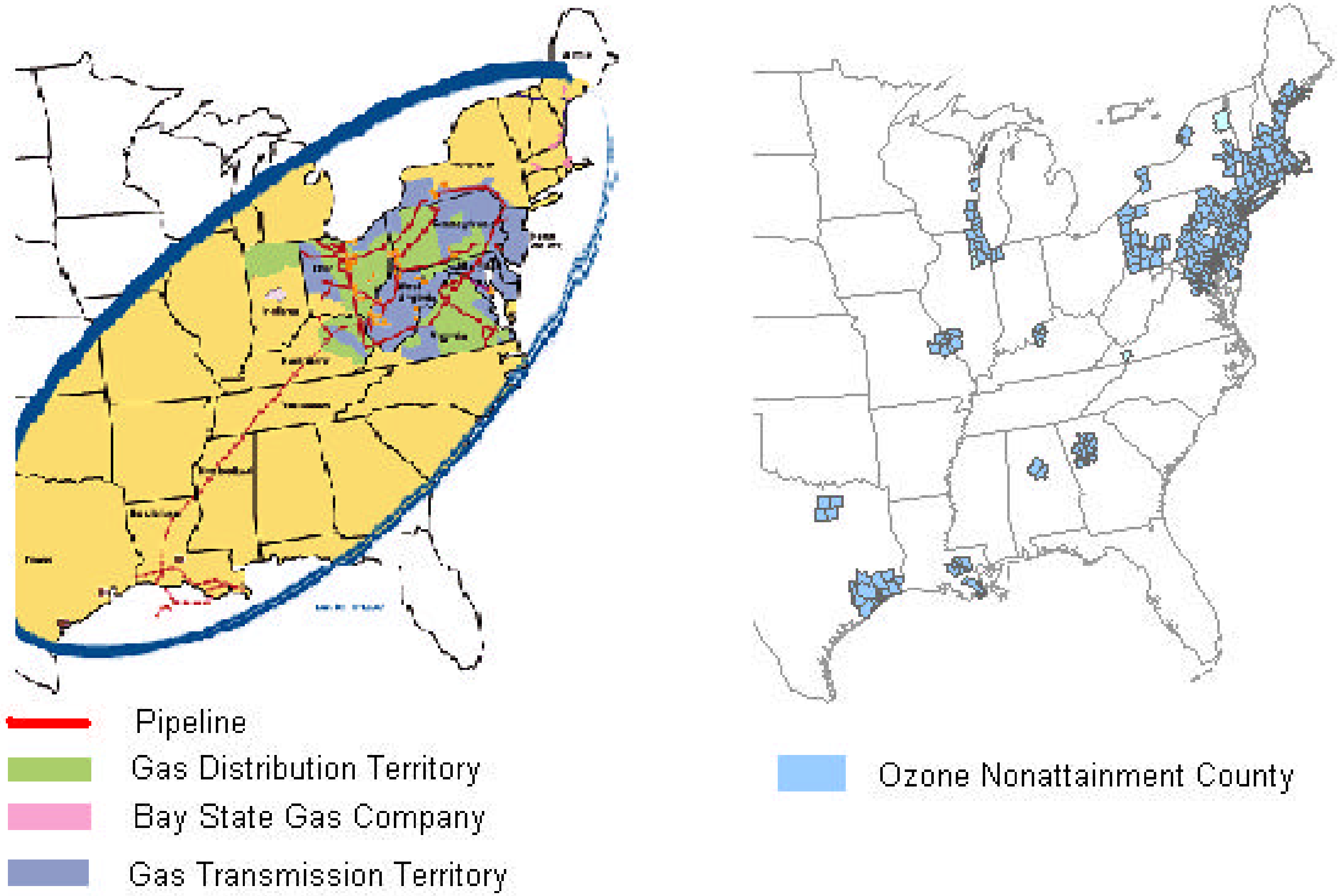


Figure 1. NiSource Gas Service Territories and Ozone Nonattainment Areas

Phase I Objectives

- NiSource Energy Technologies will develop, demonstrate, validate, and optimize two small stand-alone distributed power technologies with the goal of exceeding current reliability, availability, efficiency, and emission goals. Issues regarding the integration and interaction with the grid and other DG systems will be considered

Work Accomplished to Date

- Interconnection Issues
- Zoning and Permitting of Distributed Generation
- System Integration and Performance
- Building System Interface and Optimization Efforts Initiated (work progressing at NET and Colorado School of Mines)

Interconnection Issues

- Identify and detail the interconnection issues for CHP
  - State of the art assessed by survey.
  - Characteristics of distribution systems.
  - Physical grid interconnection practices and associated issues.
  - Interconnection tests.
  - Delays associated with interconnection issues.
  - Impact on practices on the cost of interconnection.

Survey

- **Survey of utility requirements on key technical issues**
  - Contacted more than 100 major investor-owned utilities from across the nation. 17 of the contacted utilities replied.
  - Analyzed data according to generator classification, disconnect switch requirements, applicable codes and standards, protective relaying specifications, isolation transformer requirements, and power quality requirements.

Comparison of Manual Disconnect Requirements Among Surveyed Utilities

- 13 have Visible Break requirements
- 7 have Load Break Capability requirement
- 17 have Utility Accessibility requirement
- 16 require Utility Lock Ability of disconnect
- 12 require Clear Labeling of Disconnect

Comparison of Power Quality Specifications Among Surveyed Utilities

- 11 reference IEEE 519-1992
- 8 have references to Power Quality Requirements
- 3 have general statement regarding power quality
- Other individual requirements

Survey Conclusions

- There is much diversity about the need for CHP.
- Most utilities don't consider CHP as a major electric system consideration in the near or long term.
- Volatility in the CHP device market restricts planning.
- Local Building inspectors are often not greatly concerned with CHP. Generally they look to NEC.
- Standards need to be supplemented for general use. Locally there is a lack of understanding as to how it will all fit together and what it will actually mean to operations. DG Road Show is good start.
- The benefits of CHP need to be made clear to illustrate common benefit. CHP can provide a partial solution to insufficient electric transmission capabilities and constraints.

Zoning and Permitting of Distributed Generation

– **Identify zoning and permitting requirements and assess the associated costs for installing DP systems within the NiSource service area.**

General Observations

- Building codes generally adopted on a state-by-state basis. Usually will adopt one of the national codes. Then adopt amendments to bring into compliance with the states' laws.
- The National Electric Code is the only national code used throughout the US. Does not directly address DG.

State Building Codes (NiSource Territory)

State	Adopted State Building Code	DG Amendments
Indiana	Unified Building Code	No
Kentucky	BOCCA	No
Maine	None	No
Maryland	International Building Code	No
Mass.	BOCCA	No
New Hampshire	None	No
Ohio	BOCCA	Yes
Penn.	Title 34 Pennsylvania’s Fire & Panic Code	No
Virginia	BOCCA	No

Emissions Levels

- According to State Regulations
- Several special exemptions for CHP in several States at the 30 and 200 kW level.

Zoning and Permitting Conclusions

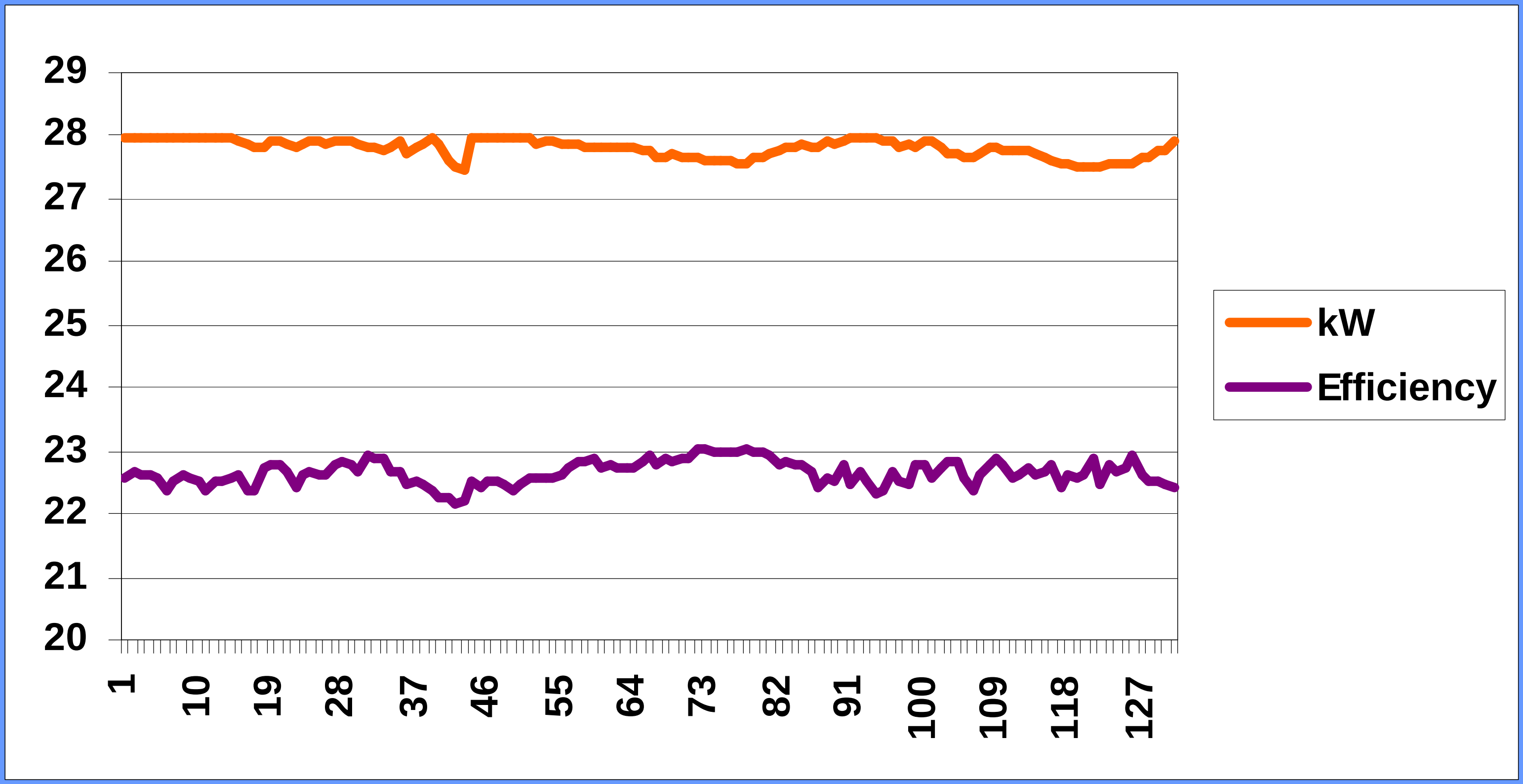
- There is no general approach to zoning of CHP.
- Zoning regulations are State by State.
- Generally little knowledge of CHP issues by local building inspectors.
- Local municipalities vary widely in their level of understanding and receptiveness to new technologies including CHP.

System Integration and Performance

- Benchmark the performance of 2 DG systems, including reliability, emissions, efficiency, etc.
- Monitor the performance of power electronics systems
- Evaluate performance relative to the grid
- Definition of tracking and control systems

DG Test System 1
Commercial Building
Chesterton, In

DG Test System 1 Efficiency vs Output and Time (hrs)



DG Test System 1
Building Model

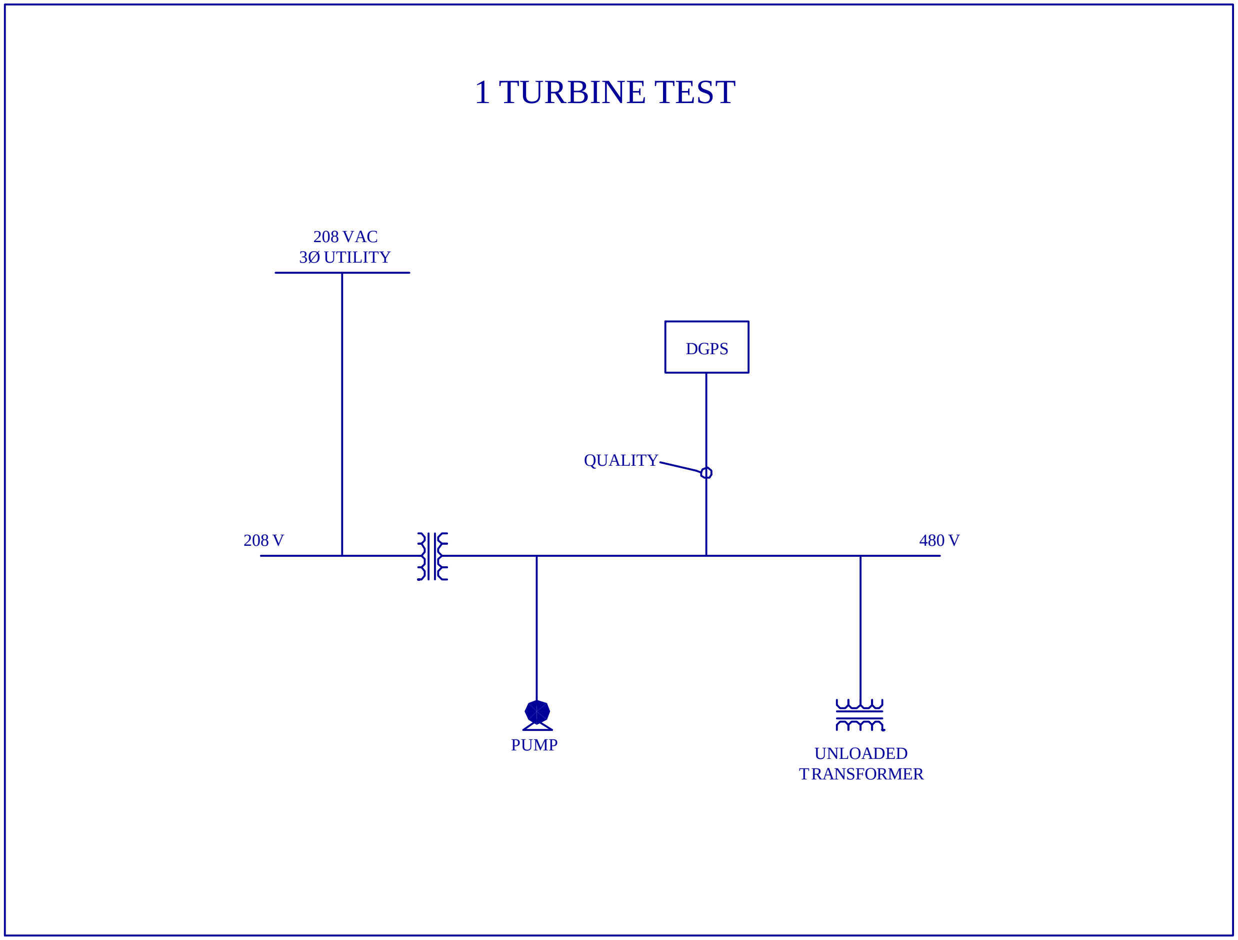
- A preliminary building model had been developed and is in operation.
  – First step in considering integration of the building into the CHP system.
  – Preliminary test results are promising.
  – Building control modifications are in process.
  – Work progressing at NET and Colorado School of Mines

DG Test System 2
Test Facility
Gary, IN

- Test system constructed to consider:
  - Micro turbine performance
  - Response of micro turbines to each other, with energy storage devices (fly wheel), and interaction with the grid.
  - Power Quality
  - Transient response

DG Test System 2
Fly Wheel And Pump Loads

DG Test System 2
Turbine #1 Test

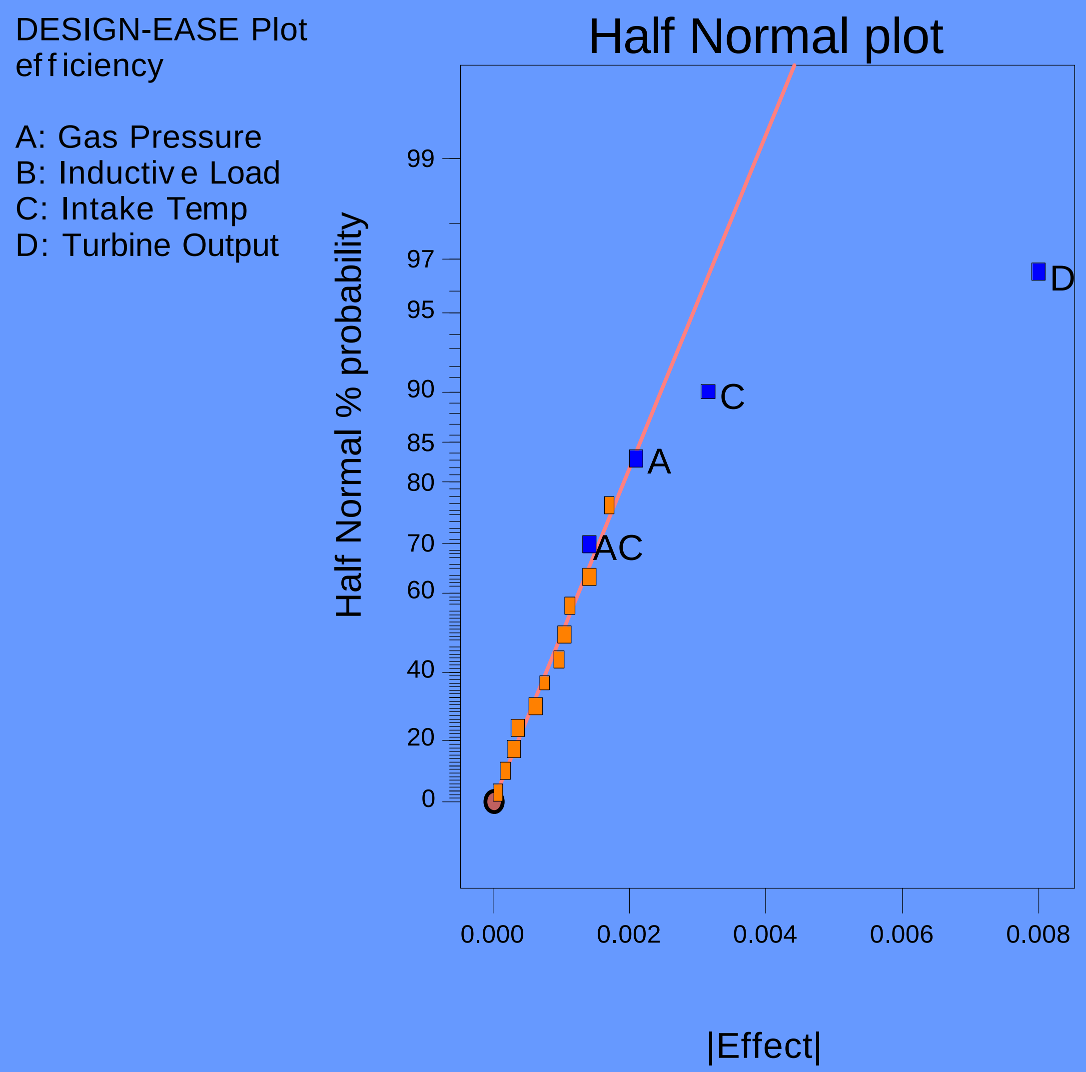


Test 1 Experimental Design

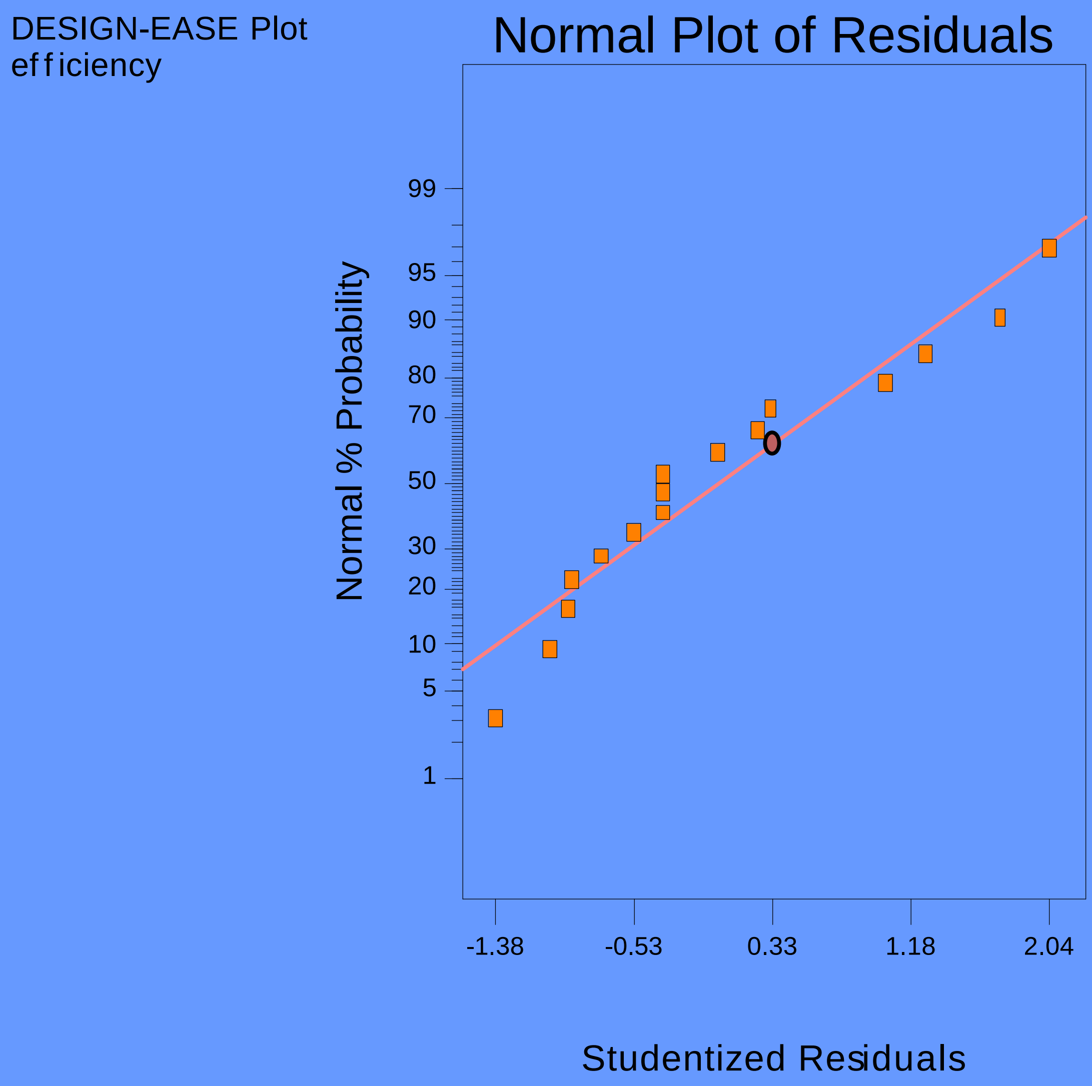
The following table describes the experimental design for test 1.

Order		Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Std	Run	Gas Pressure	Transformer (inductor)	Intake Temp	Turbine Output	Efficiency (fraction)	THD (current)
11	1	5.00	on	80.00	24.00	0.1901	0.0268
13	2	5.00	off	90.00	24.00	0.1866	0.0294
9	3	5.00	off	80.00	24.00	0.1871	0.0268
1	4	5.00	off	80.00	16.00	0.1824	0.0294
6	5	10.00	off	90.00	16.00	0.1825	0.0422
4	6	10.00	on	80.00	16.00	0.1803	0.0403
8	7	10.00	on	90.00	16.00	0.1779	0.0386
10	8	10.00	off	80.00	24.00	0.1892	0.0314
5	9	5.00	off	90.00	16.00	0.1753	0.0464
16	10	10.00	on	90.00	24.00	0.1863	0.0294
2	11	10.00	off	80.00	16.00	0.1815	0.0458
14	12	10.00	off	90.00	24.00	0.1869	0.0361
12	13	10.00	on	80.00	24.00	0.1897	0.0293
7	14	5.00	on	90.00	16.00	0.1753	0.0376
3	15	5.00	on	80.00	16.00	0.1783	0.0404
15	16	5.00	on	90.00	24.00	0.1823	0.0308

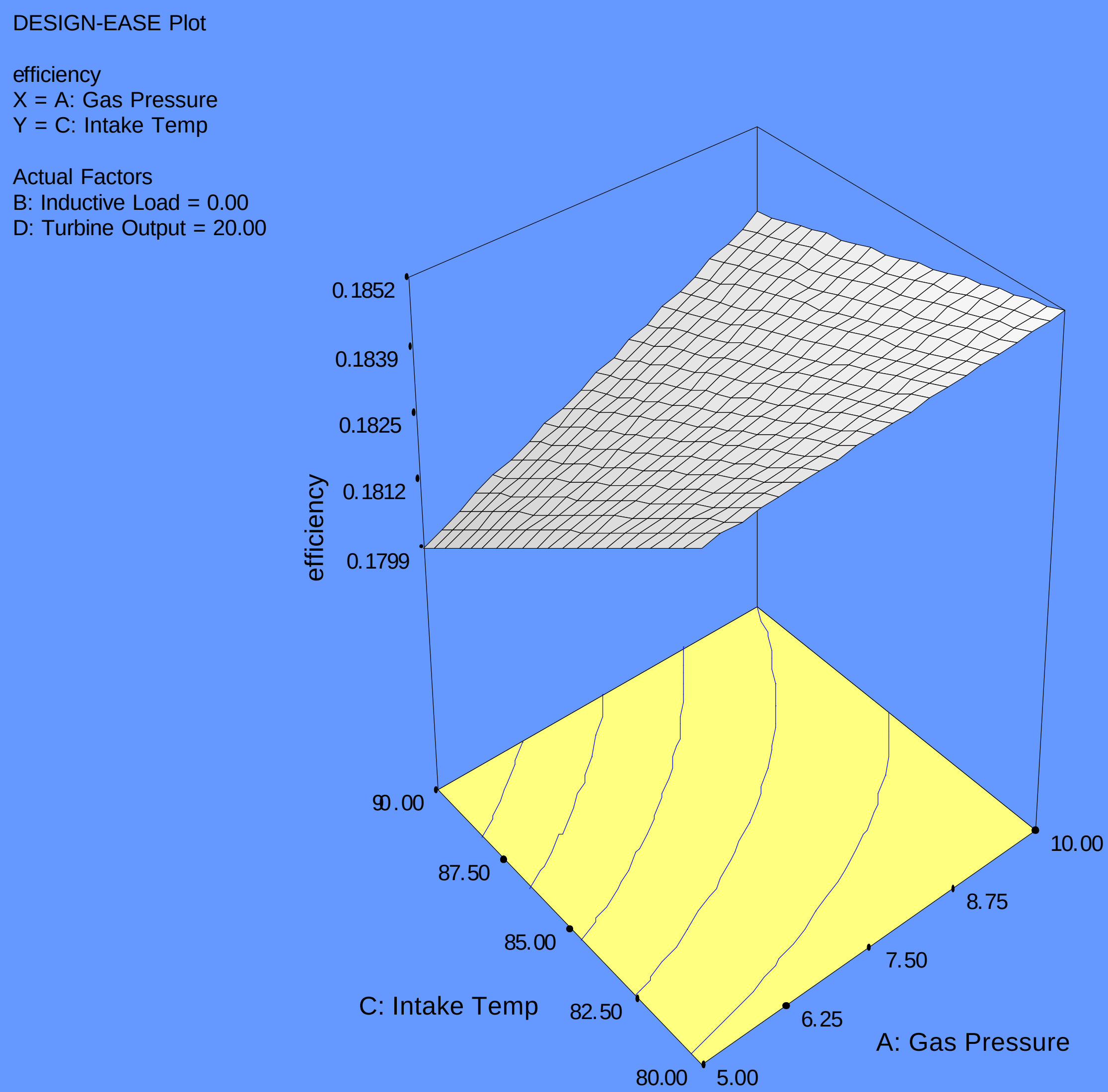
DG Test System 2
Turbine 1 Test
Experimental Model Parameter Identification



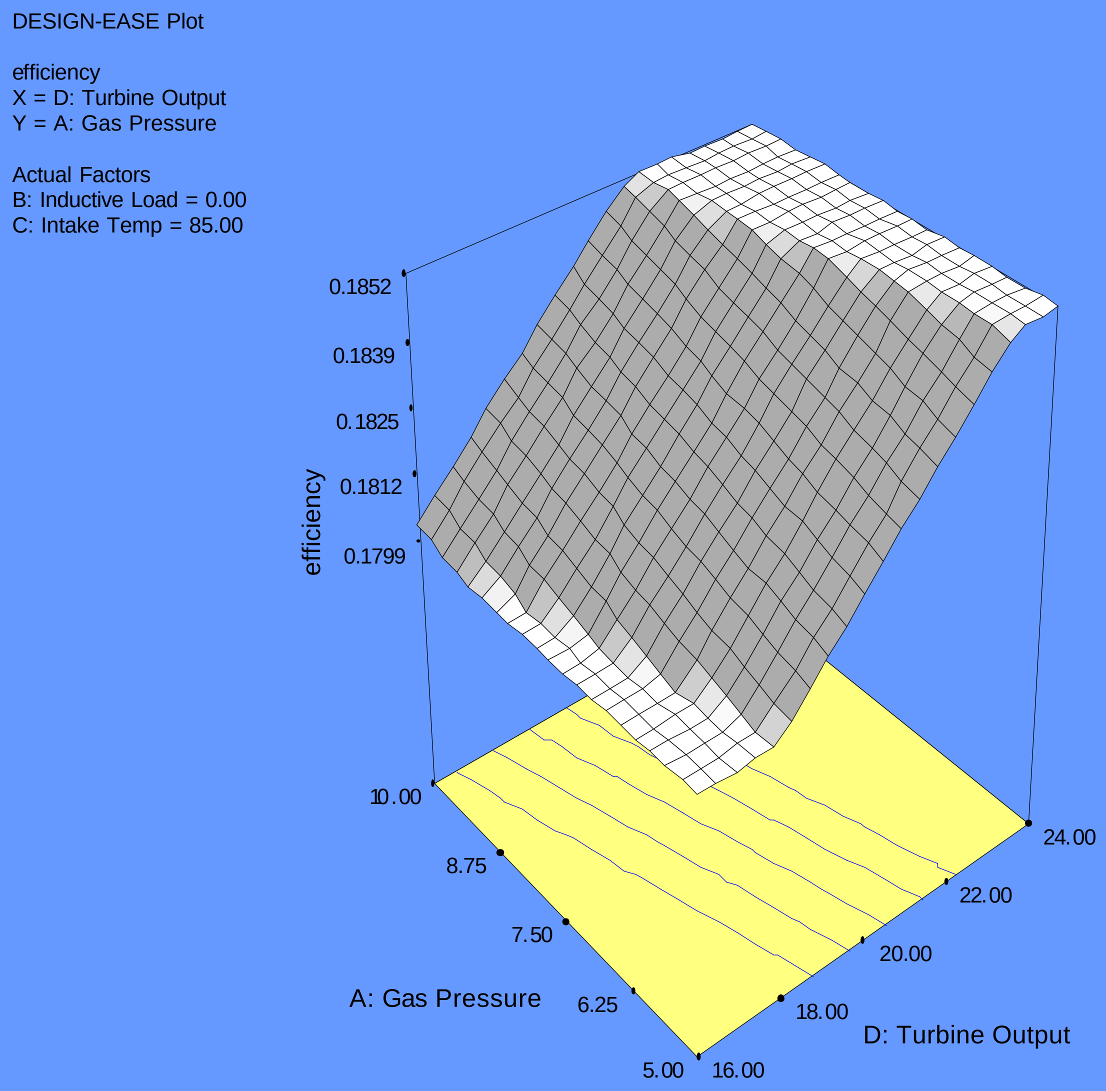
DG Test System 2
Turbine 1 Test
Experimental Model Parameter Verification



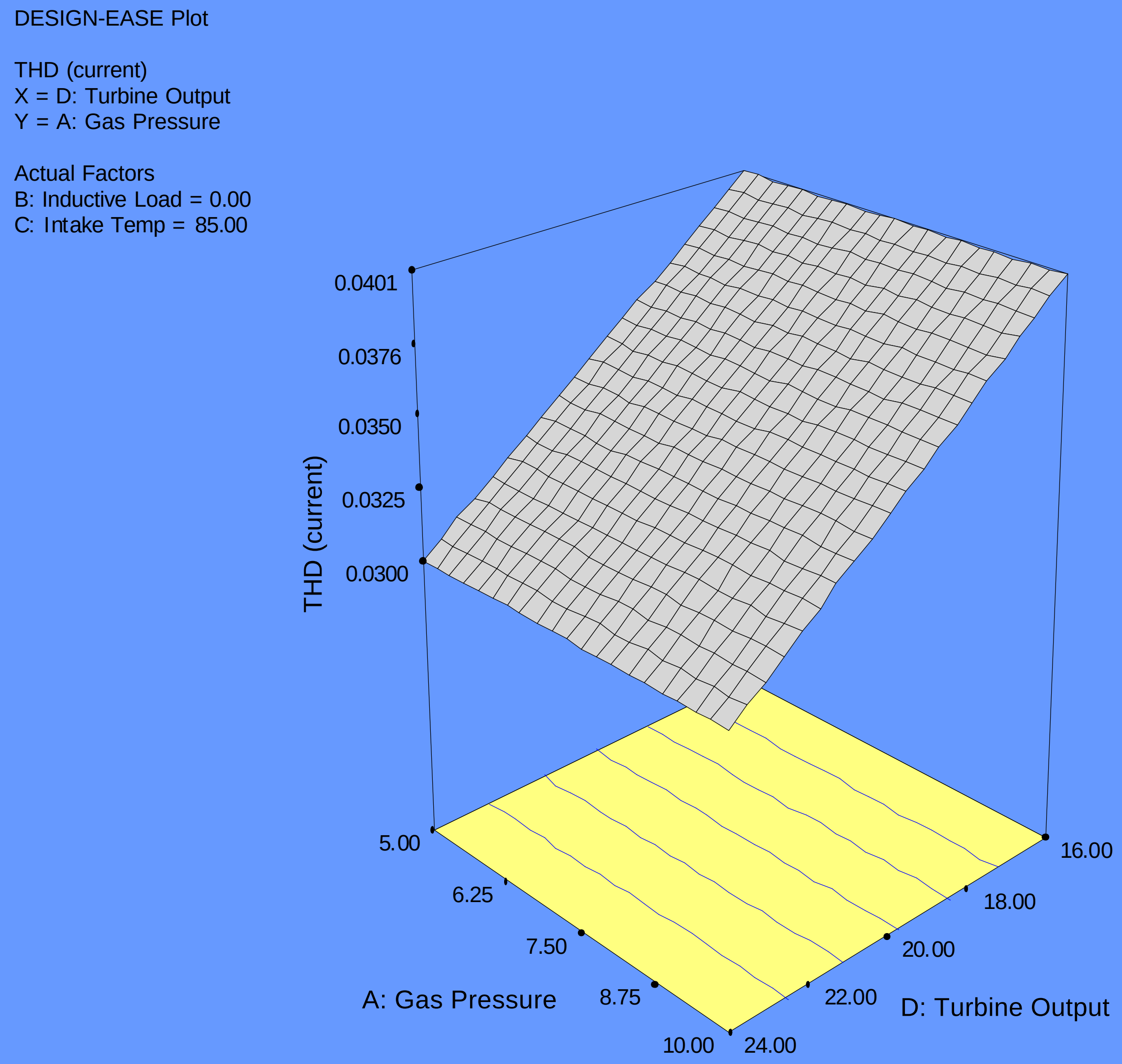
DG Test System 2
Turbine 1 Test
Experimental Model Parameter Results



DG Test System 2
Turbine 1 Test
Experimental Model Parameter Results



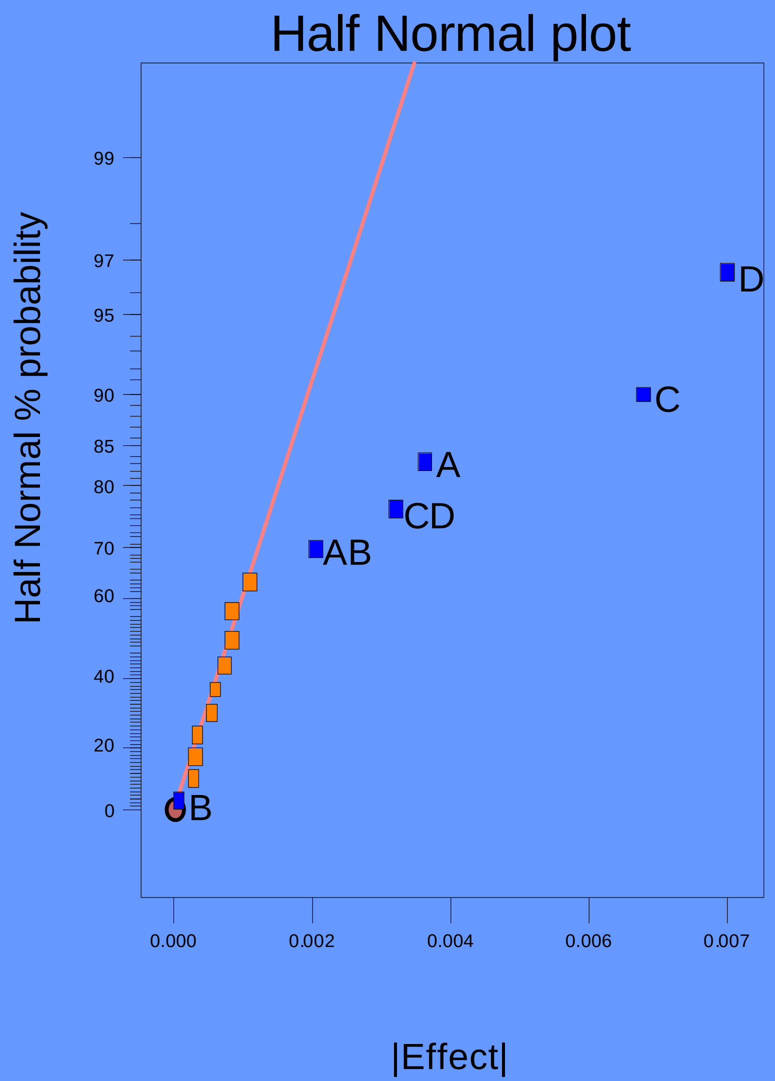
DG Test System 2
Turbine 1 Test
Experimental Model Parameter Results



DG Test System 2
Turbine 2 Test
Experimental Model Parameter Identification

DESIGN-EASE Plot
efficiency

A: Gas Pressure
B: Inductive Load
C: Intake Temp
D: Turbine Ouput

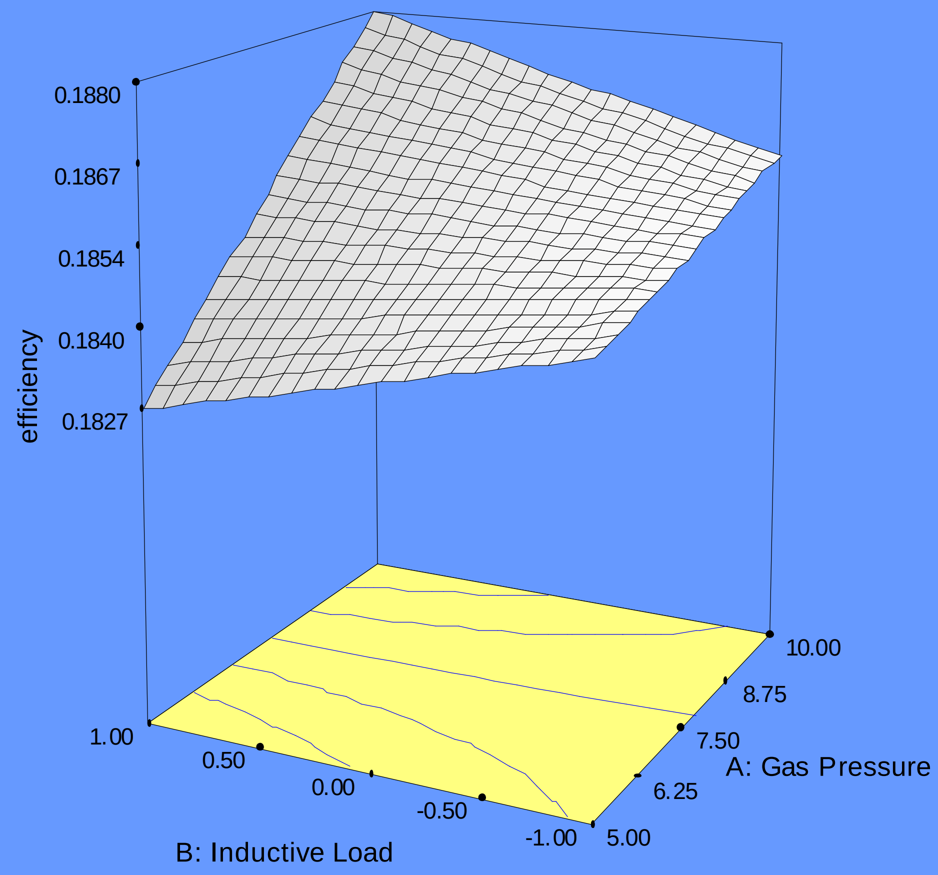


DG Test System 2
Turbine 2 Test
Experimental Model Parameter Results

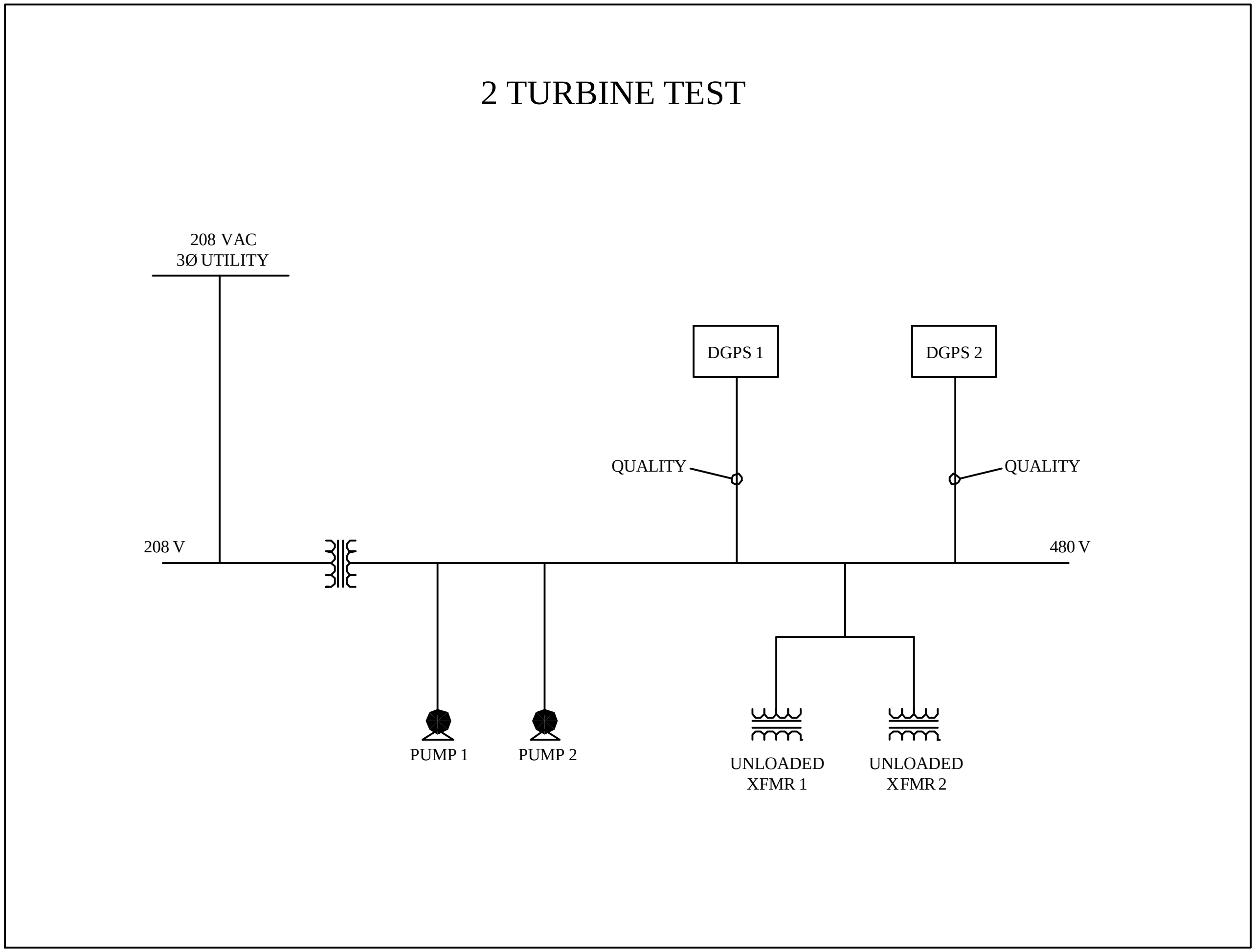
DESIGN-EASE Plot

efficiency
X = A: Gas Pressure
Y = B: Inductive Load

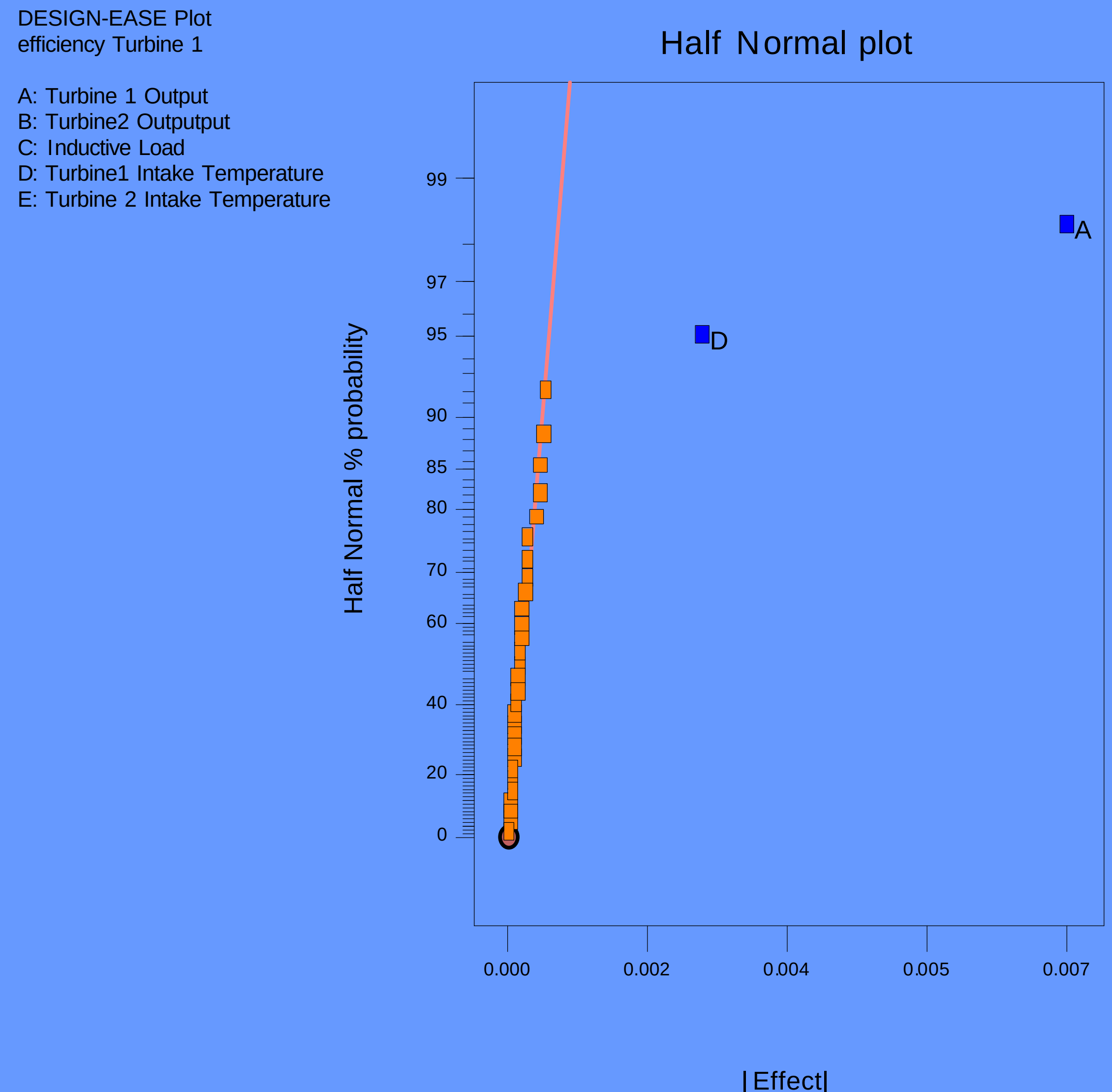
Actual Factors
C: Intake Temp = 85.00
D: Turbine Ouput = 20.00



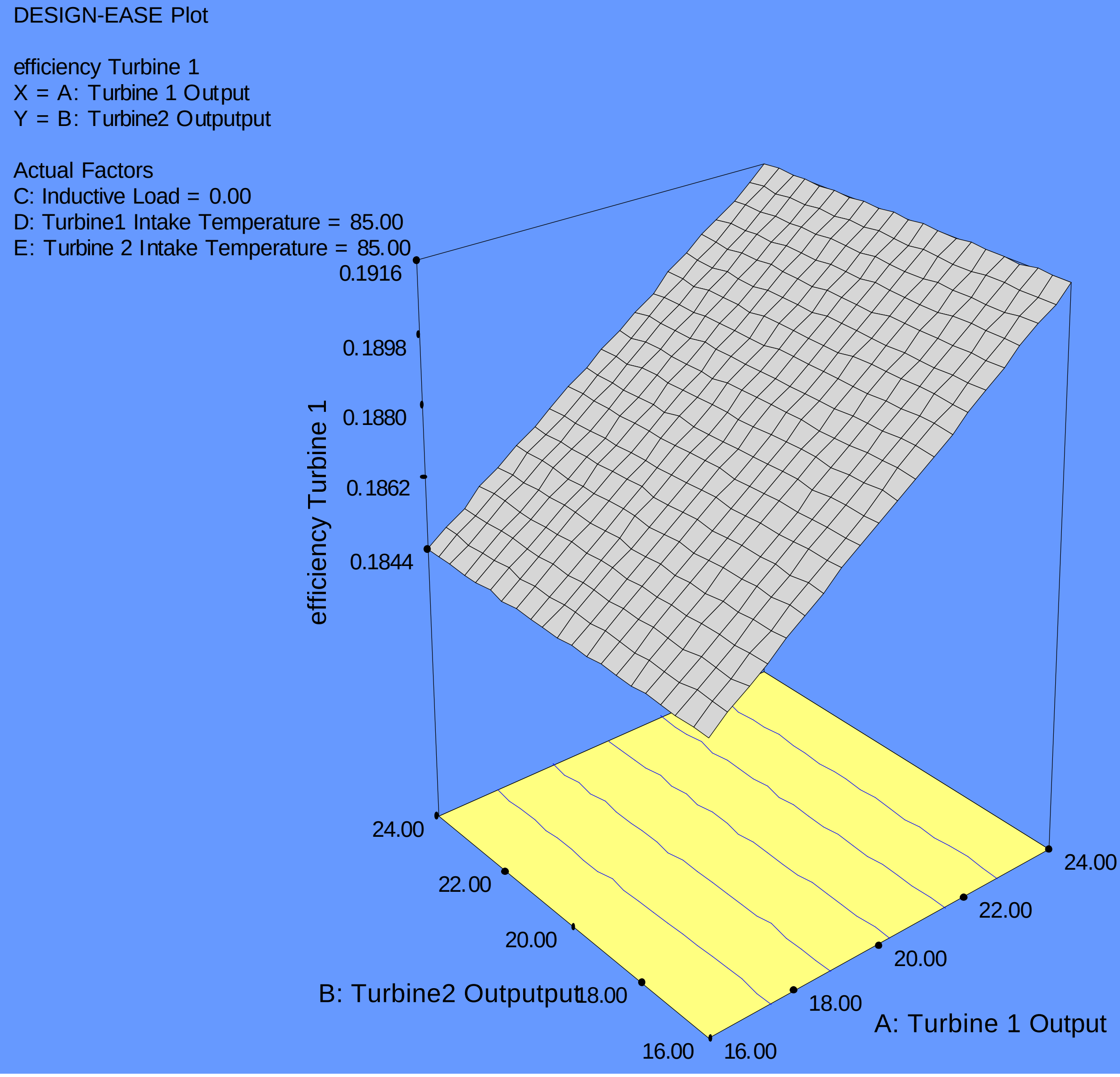
DG Test System 2
2 Turbine Test



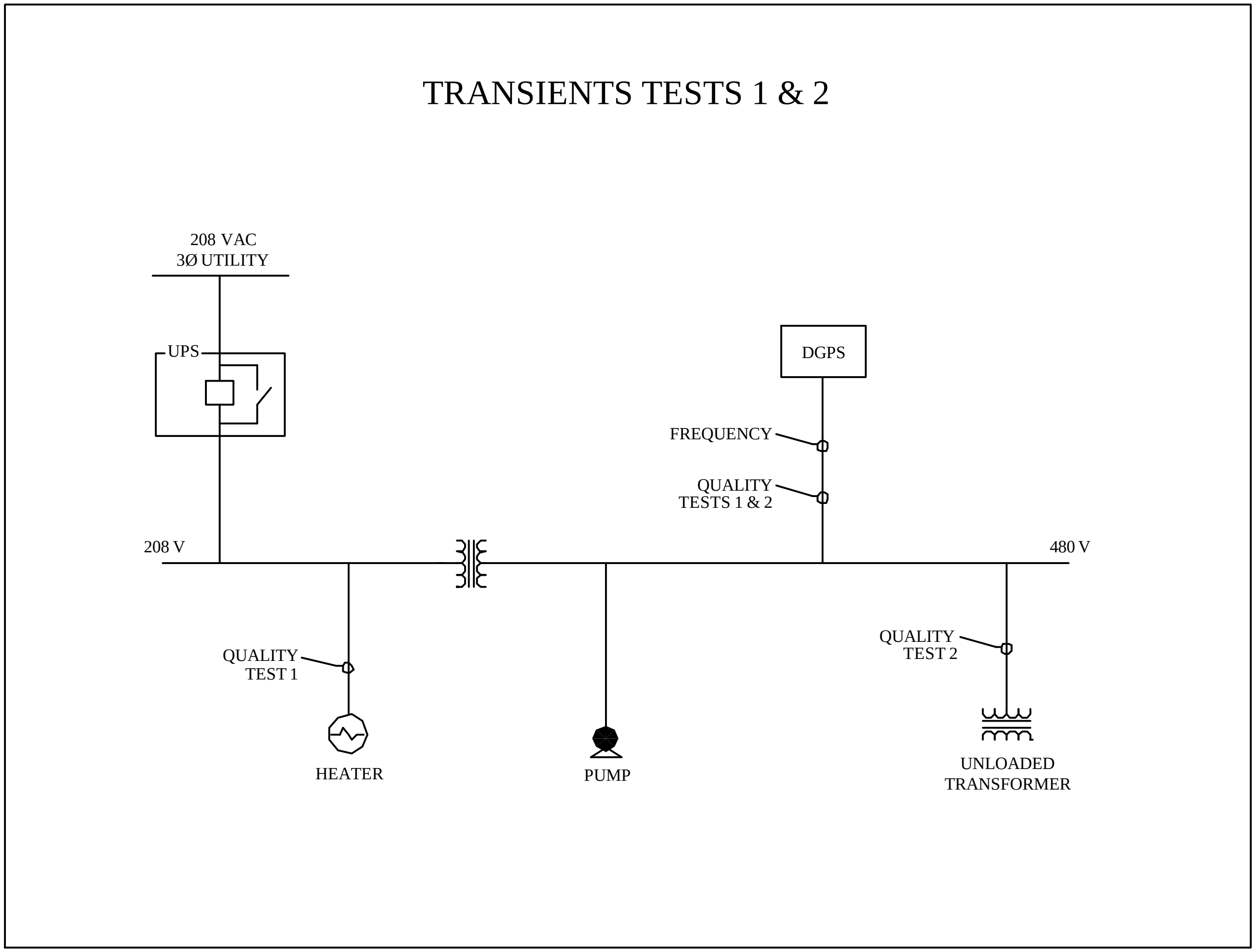
DG Test System 2
2 Turbine Test
Experimental Model Parameter Results



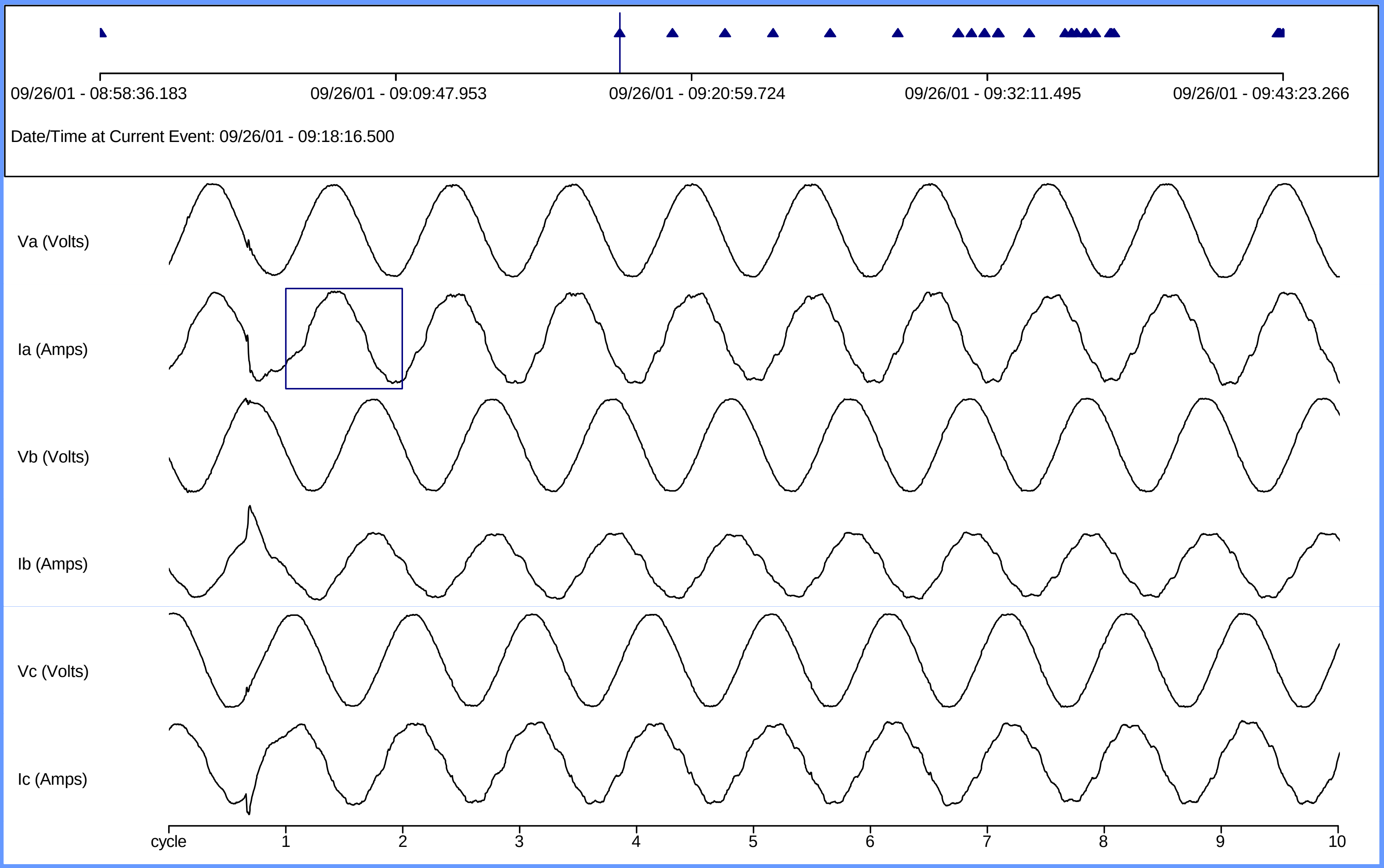
DG Test System 2
2 Turbine Test
Experimental Model Parameter Results



DG Test System 2
Transient Test



DG Test System 2
Resistive Transient Test

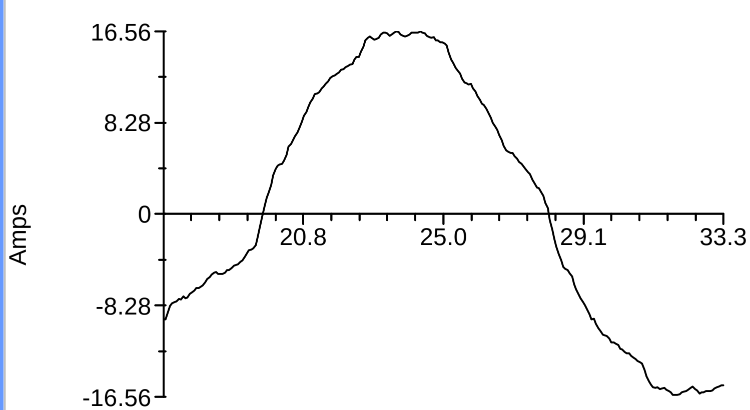


DG Test System 2
Resistive Transient Test

Event: 4 Of 40 — Event Trigger Input 5 Vc Volts (LOWER)

Duration: 21 Cycles — Event Trigger Cycle 1

Time:	09/26/01 09:18:16.500
Input:	Ia Amps
Cycle:	2

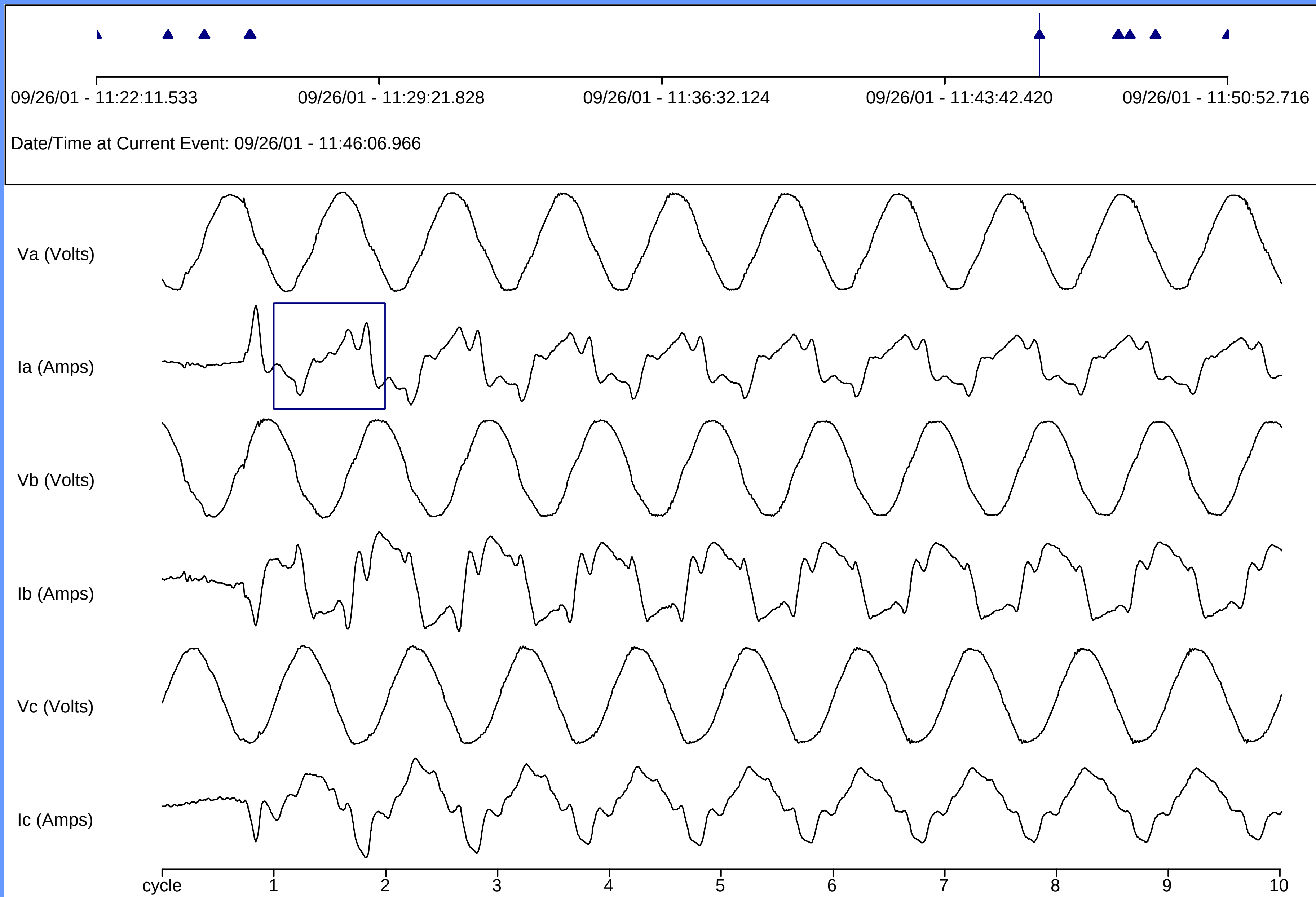


Cycle Waveform

Total Harmonic Distortion	11.48 %
Odd Contribution	9.09 %
Even Contribution	7.01 %
RMS Of Fundamental	11.27 A
RMS Of Fund + Harm	11.36 A
K Factor	2.19

Harm	% Of Fund	Amps	Angle	Harm	% Of Fund	Amps	Angle
Fund	100.00	11.3	0°	2	3.95	0.4	176°
3	4.06	0.5	243°	4	3.89	0.4	269°
5	6.78	0.8	300°	6	2.79	0.3	14°
7	1.78	0.2	334°	8	1.41	0.2	93°
9	1.24	0.1	185°	10	0.56	0.1	264°
11	3.07	0.3	310°	12	1.48	0.2	17°
13	0.86	0.1	21°	14	0.76	0.1	131°
15	0.91	0.1	200°	16	1.07	0.1	272°
17	1.32	0.1	281°	18	1.05	0.1	356°
19	0.25	0.0	143°	20	0.32	0.0	166°
21	0.44	0.0	169°	22	0.61	0.1	297°
23	0.81	0.1	255°	24	0.82	0.1	346°
25	0.53	0.1	72°	26	0.45	0.1	142°
27	0.45	0.1	190°	28	0.64	0.1	249°
29	0.30	0.0	285°	30	0.15	0.0	327°
31	0.47	0.1	71°	32	0.27	0.0	126°
33	0.28	0.0	232°	34	0.50	0.1	279°
35	0.28	0.0	330°	36	0.43	0.0	28°
37	0.38	0.0	44°	38	0.04	0.0	218°
39	0.40	0.0	194°	40	0.35	0.0	301°
41	0.27	0.0	315°	42	0.46	0.1	350°
43	0.10	0.0	320°	44	0.26	0.0	160°
45	0.19	0.0	178°	46	0.52	0.1	257°
47	0.28	0.0	324°	48	0.16	0.0	47°
49	0.09	0.0	84°	50	0.29	0.0	155°
51	0.22	0.0	205°	52	0.21	0.0	291°
53	0.17	0.0	356°	54	0.20	0.0	45°
55	0.18	0.0	118°	56	0.27	0.0	164°
57	0.17	0.0	220°	58	0.09	0.0	303°
59	0.18	0.0	328°	60	0.18	0.0	51°
61	0.22	0.0	123°	62	0.12	0.0	162°
63	0.18	0.0	239°				

DG Test System 2
Inductive Transient Test (Grid Isolated)



DG Test System 2
Inductive Transient Test (Grid Isolated)

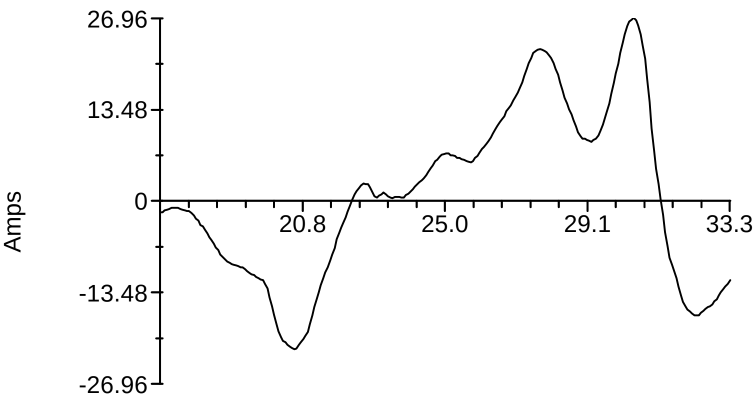
Event: 9 Of 17

Duration: 21 Cycles

Event Trigger Input 6 Ic Amps (THD)

Event Trigger Cycle 1

Time:	09/26/01 11:46:06.967
Input:	Ia Amps
Cycle:	2



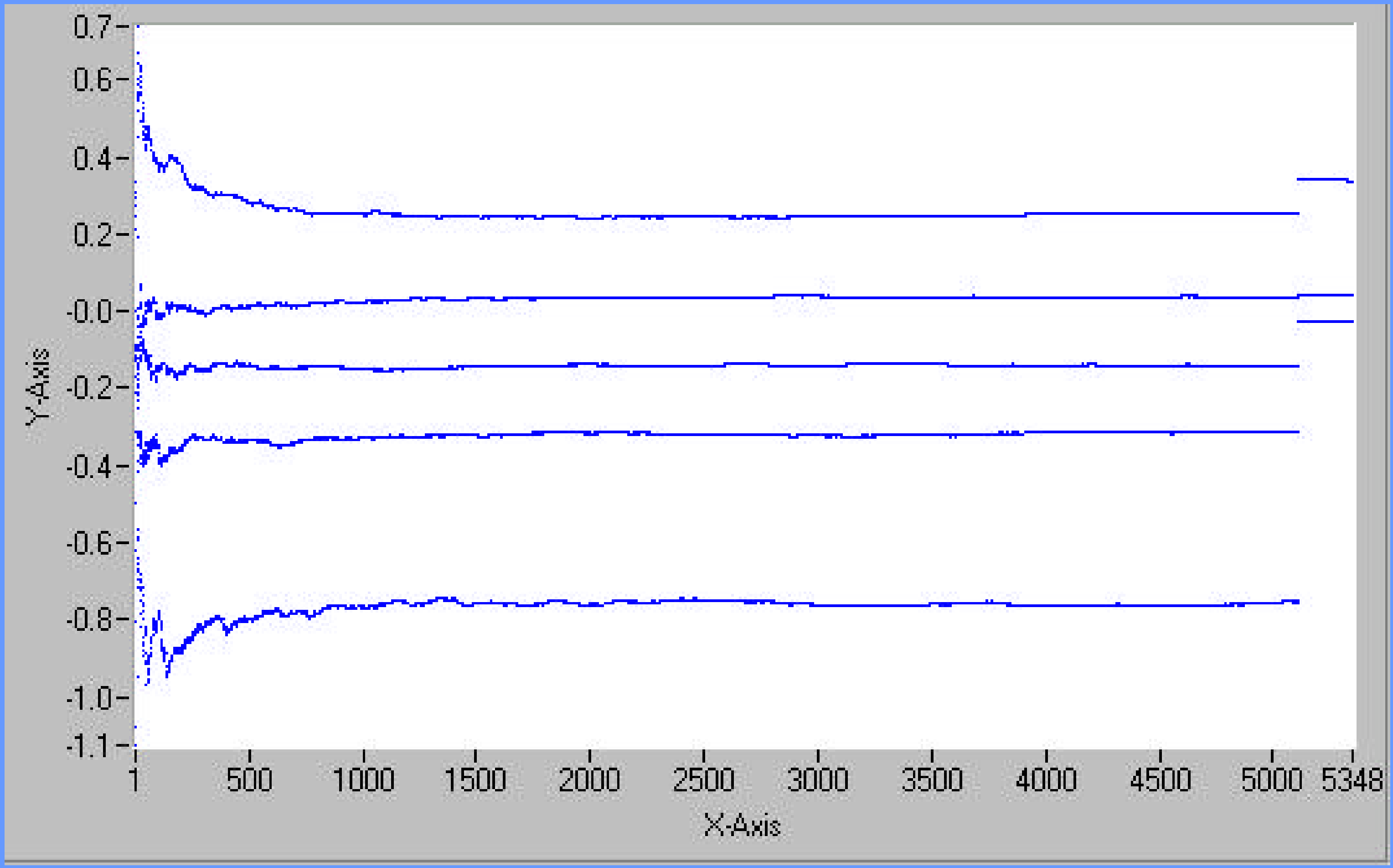
Cycle Waveform

Total Harmonic Distortion	68.80 %
Odd Contribution	44.14 %
Even Contribution	52.77 %
RMS Of Fundamental	10.44 A
RMS Of Fund + Harm	12.70 A
K Factor	9.73

Harm	% Of Fund	Amps	Angle	Harm	% Of Fund	Amps	Angle
Fund	100.00	10.4	0°	2	14.02	1.5	242°
3	36.29	3.8	88°	4	36.83	3.8	205°
5	22.52	2.4	51°	6	33.43	3.5	265°
7	5.21	0.5	118°	8	7.94	0.8	14°
9	7.40	0.8	207°	10	2.56	0.3	38°
11	5.01	0.5	233°	12	5.15	0.5	54°
13	0.48	0.1	19°	14	0.05	0.0	338°
15	1.25	0.1	59°	16	1.65	0.2	219°
17	2.14	0.2	47°	18	2.28	0.2	190°
19	1.12	0.1	326°	20	0.93	0.1	182°
21	0.51	0.1	308°	22	1.00	0.1	86°
23	1.63	0.2	215°	24	1.02	0.1	322°
25	0.88	0.1	179°	26	0.78	0.1	334°
27	0.57	0.1	90°	28	0.70	0.1	257°
29	0.81	0.1	22°	30	0.61	0.1	153°
31	0.98	0.1	344°	32	0.83	0.1	164°
33	0.63	0.1	311°	34	0.59	0.1	60°
35	0.15	0.0	160°	36	0.63	0.1	21°
37	0.74	0.1	131°	38	0.86	0.1	307°
39	1.04	0.1	111°	40	0.60	0.1	279°
41	0.67	0.1	85°	42	0.57	0.1	195°
43	0.23	0.0	356°	44	0.39	0.0	147°
45	0.60	0.1	263°	46	0.58	0.1	65°
47	0.49	0.1	221°	48	0.42	0.0	46°
49	0.58	0.1	183°	50	0.34	0.0	312°
51	0.32	0.0	107°	52	0.42	0.0	251°
53	0.47	0.0	56°	54	0.43	0.0	210°
55	0.42	0.0	355°	56	0.37	0.0	139°
57	0.38	0.0	281°	58	0.42	0.0	76°
59	0.37	0.0	238°	60	0.40	0.0	37°
61	0.41	0.0	177°	62	0.35	0.0	328°
63	0.37	0.0	120°				

DG Test System 2
Inductive Transient Test (Grid Isolated)
Stability Consideration

Lyapunov Spectrum Phase A Current
Inductive Transient



DG Test Systems 1 & 2
Conclusions

- The micro turbines performed reliably with efficiency as quoted by manufacturer for the temperature and pressure conditions.
- Efficiency depends on temperature, gas pressure, and output level.
- Heat recovery imposed no change on the operation of the turbine.
- In a grid isolated mode, there are concerns with inductive transients and stability.
- Several component reliability issues were identified and are being considered by the manufacturer.

Environmental Tests

Emissions were measured under various turbine power levels.

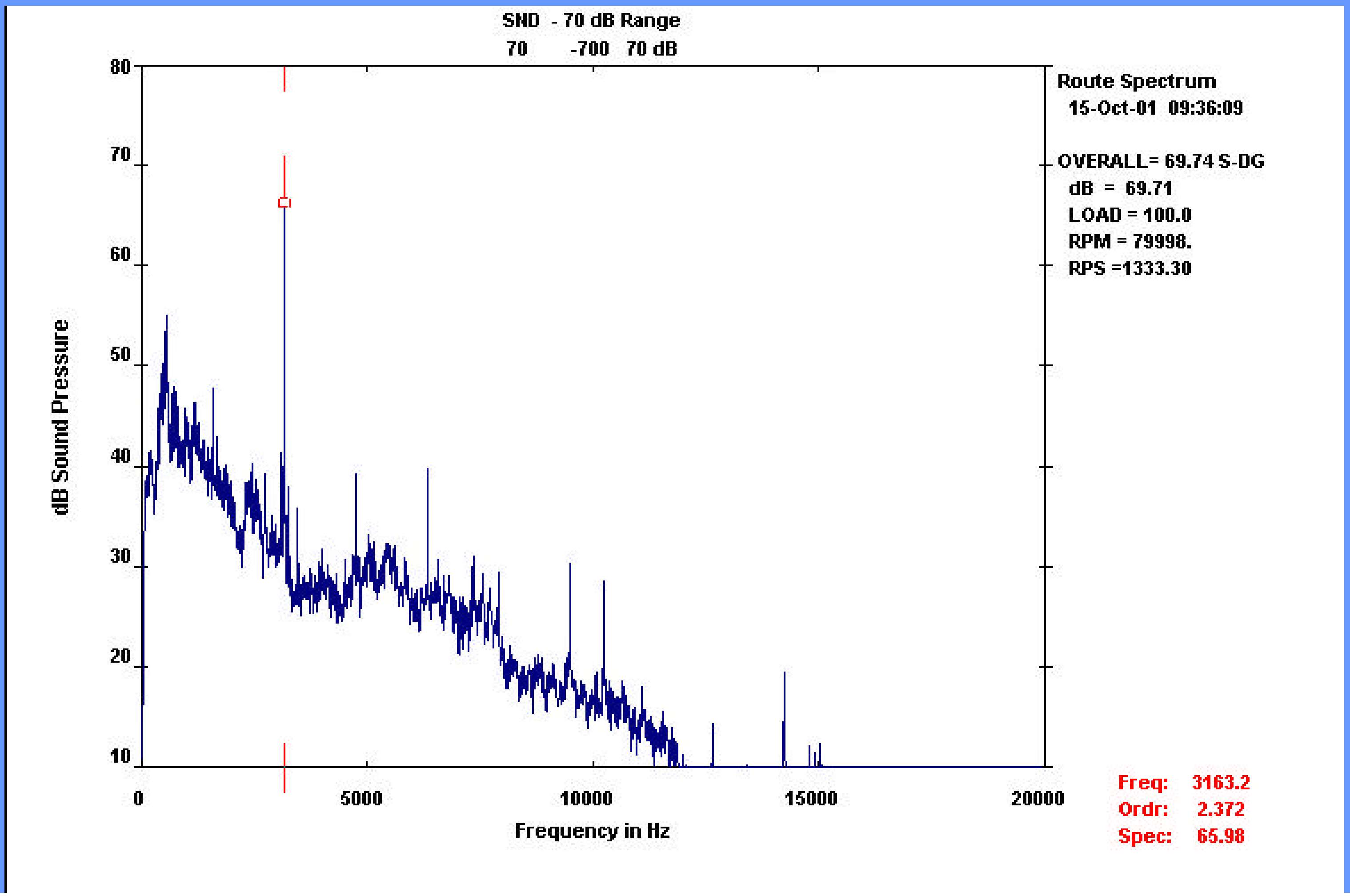
Test No.	Date	Time	Load KW	Flow dscfm	NO_x ppmvd	CO ppmvd
1	09/07/01	0857-0957	28	460.1	1.0	36.2
2	09/07/01	1018-1118	28	461.7	0.9	32.2
3	09/07/01	1143-1243	28	467.7	0.9	28.9
Average				463.2	0.9	32.4

Environmental Test Conclusions

- The units had emissions comparable to results quoted by the manufacturer on average.
- Emissions levels were highly dependent on the power level.

Acoustic Measurements

Acoustic measurements were recorded at various locations about the unit to determine noise levels at different distances and positions.

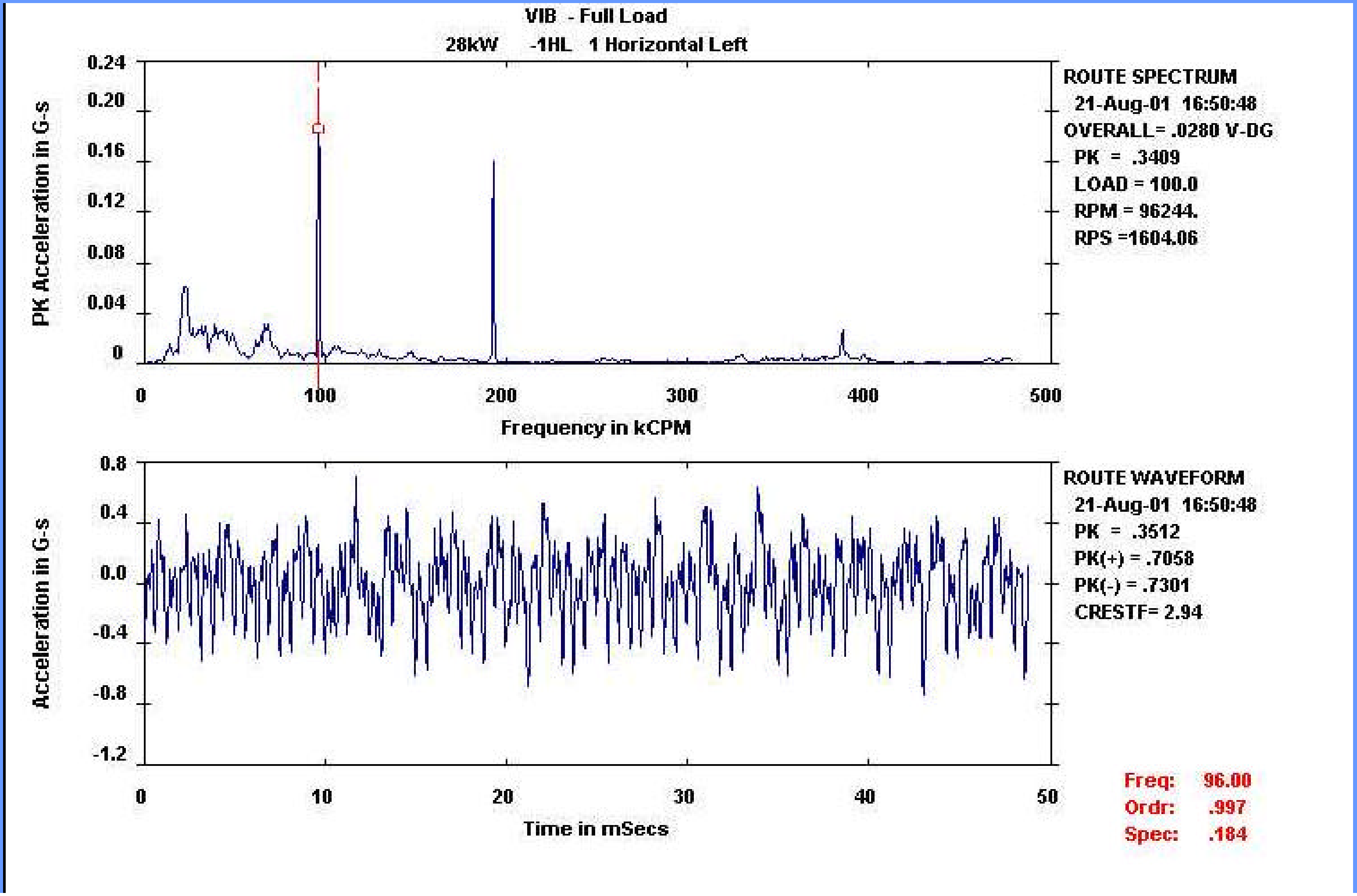


Acoustic Test Conclusions

- The units performed in accordance with manufacturer specifications for noise.
- The high frequency part of the spectrum is of concern for some applications.
- The noise is emitted relatively symmetrically about the plane of the unit with more noise going straight up.

Vibration Measurement

Vibration measurements were performed at various locations on the turbine.



Vibration Measurement Conclusions

- Vibration levels are negligible.
- It wasn't possible to detect any noticeable vibration external to the unit.

Building System Interface and Optimization

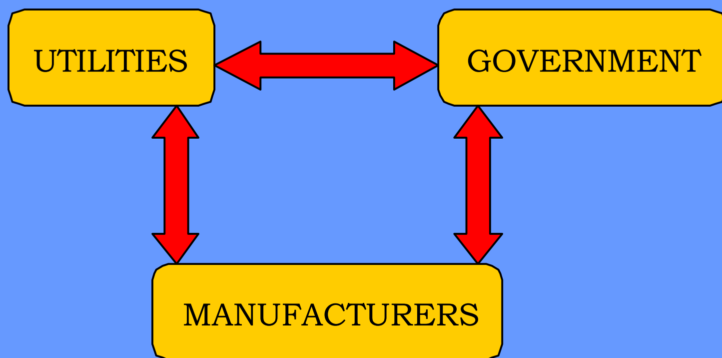
- **Test site 1 model work continues and work to include CHP options in existing building energy system has commenced.**
- **Test site 2 activities continue and have been expanded to include 2 BCHP developments.**
  - A building has been modeled. The building will have its design modified to consider efficiency and operating characteristics of a building optimized to use CHP. Inter connection issues will also be considered.
    - Sky lights and windows will be added.
    - New heating system will be added to utilize CHP heat.
    - Dehumidification and cooling alternatives will be tested.
  - A warehouse is being modeled. The building will have its energy system modified to consider the influence of CHP on the building operation and economics. Interconnection issues will also be considered.
- **BCHP optimizing model continues under development. Efforts underway at NET and Colorado School of Mines.**
- **Interconnection issues will be considered further.**

Project Conclusions

- Issues related to the connection of Distributed Generation to the grid were identified. A survey was completed to assess the current situation.
- Zoning and permitting requirements for Distributed Generation were identified within the NiSource territory. Various surveys of local and state authorities were conducted.
- Two test systems were constructed and operated to determine the viability of the technology and analytic models alone and in conjunction with other devices and the grid. An operating data base of information was constructed. A statistical experimental design was employed to maximize the benefit from the experimental effort.
- Activities have recently been extended to consider building design aspects that can be used to optimize CHP applications. Facility construction and test program development are currently underway. This area shows significant promise for improved efficiency.

Attachments

Interaction Between Standards Contributing Organizations



A comparison of manual disconnect requirements among surveyed utilities.

Utility	Visible Break	Load Break Capability	Utility Accessible	Utility Lockable	Clear Labeling of Disconnect
1	? *	?	?	?	?
2	NS	?	?	? **	NS
3	?	NS	?	?	?
4	?	NS	?	?	NS
5	?	?	?	?	NS
6	?	?	?	? ***	NS
7	?	NS	?	?	NS
8	NS	NS	?	?	NS
9	?	?	?	? **	?
10	?	NS	?	? **	?
11	?	NS	?	? **	NS
12	NS	NS	?	?	NS
13	NS	NS	?	NS	NS
14	?	NS	?	?	NS
15	?	NS	?	?	NS
16	?	?	?	?	NS
17	?	?	?	? **	?

***Definition of “visibly open” requires that the switch blades, jaws, and air gap between them be clearly visible in OPEN position. View of these components can not be obscured by the arc shield or switch case. It is uncertain whether such switches are readily available.**

****Utility lockable in OPEN position only.**

*****Utility lockable in OPEN and CLOSED positions.**

? **= Required by standard.**

NS = Not Specified in standard.

Utility 13 only calls for intertie circuit breaker device, on generator side.

Exemption Levels in NI Territory

State	Exemption Levels (emissions less than the following amounts)								Special Exemptions
	NO_x	CO	VOC	PM_{10}	SO_2	Pb	Single	Total HAP	
Kentucky (1)	5 tpy	5 tpy	5 tpy	5 tpy	5 tpy		2 tpy	5 tpy	
Indiana (1)	10 tpy	25 tpy	10 tpy	5 tpy	10 tpy				
Ohio (1)	10 lb per 24	10 lb per 24	10 lb per 24	10 lb per 24	10 lb per 24		1 tpy		Natural gas combustion less than
Virginia (1)	40 tpy	100 tpy	25 tpy	15 tpy	40 tpy	0.6 tpy			Gaseous fuel combustion less than
Pennsylvania (1)									Natural gas combustion less than
Maryland (1)									Natural gas combustion less than 1
Massachusetts (1)									Combined combustion turbine installation less
New Hampshire (1)									Natural gas combustion less than
Maine (1)									Natural gas combustion less than
West Virginia (2)	10 tpy	10 tpy	10 tpy	10 tpy	10 tpy			5 tpy	No other requirements.
Delaware (2)	0.2 lb/day	0.2 lb/day	0.2 lb/day	0.2 lb/day	0.2 lb/day	0.2 lb/day			
New Jersey (2)									Gaseous fuel combustion less than 1
New York (2)									Natural gas combustion less than
Louisiana (2)	5 tpy	5 tpy	5 tpy	5 tpy	5 tpy				Generally must obtain exemption letter.
Mississippi (2)	10 tpy	10 tpy	10 tpy	10 tpy	10 tpy		1 tpy	2.5 tpy	
Tennessee (2)									Gaseous fuel combustion less than 10 MMBtu/hr.

DG Exemptions in NI Territory

State	30 kW Exempt	200 kW Exempt	Requirements
Kentucky [1]	Yes	Yes	
Indiana [1]	Yes	Yes	
Ohio [1]	Yes	Likely[5]	
Virginia [1]	Yes	Yes	
Pennsylvania [1]	Yes	Yes	
Maryland [1]	Yes	No	More than 2 MTs at a site will
Massachusetts [1]	Yes	No	More than 6 MTs at a site will
New Hampshire [1]	Yes	Yes	
Maine [1]	Yes	Yes	
West Virginia [2]	Yes	Yes	Assumes no other local
Delaware [2]	No	No	State permitting required.
New Jersey [2]	Yes	No	More than 2 MTs at a site will
New York [2]	Yes	Yes	
Louisiana [2]	Yes	Yes	Generally must obtain an
Mississippi [2]	Yes	Yes	
Tennessee [2]	Yes	Yes	

1) NiSource Natural gas transmission and distribution territory.
(2) NiSource Natural gas transmission territory.
(3) Assumes maximum heat input of 0.43 MMBtu/hr.
(4) Assumes maximum heat input of 3.44 MMBtu/hr.
(5) Ohio exempts natural gas combustion units less than 10 MMBtu/hr. However, NO_x emissions potentially exceed the 10 lb per 24 hour exemption level creating a conflict in the regulations. A region specific determination would have to be made by the controlling Ohio agency.

Test 1 Experimental Design

The following table describes the experimental design for test 1.

Order		Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Std	Run	Gas Pressure	Transformer (inductor)	Intake Temp	Turbine Output	Efficiency (fraction)	THD (current)
11	1	5.00	on	80.00	24.00	0.1901	0.0268
13	2	5.00	off	90.00	24.00	0.1866	0.0294
9	3	5.00	off	80.00	24.00	0.1871	0.0268
1	4	5.00	off	80.00	16.00	0.1824	0.0294
6	5	10.00	off	90.00	16.00	0.1825	0.0422
4	6	10.00	on	80.00	16.00	0.1803	0.0403
8	7	10.00	on	90.00	16.00	0.1779	0.0386
10	8	10.00	off	80.00	24.00	0.1892	0.0314
5	9	5.00	off	90.00	16.00	0.1753	0.0464
16	10	10.00	on	90.00	24.00	0.1863	0.0294
2	11	10.00	off	80.00	16.00	0.1815	0.0458
14	12	10.00	off	90.00	24.00	0.1869	0.0361
12	13	10.00	on	80.00	24.00	0.1897	0.0293
7	14	5.00	on	90.00	16.00	0.1753	0.0376
3	15	5.00	on	80.00	16.00	0.1783	0.0404
15	16	5.00	on	90.00	24.00	0.1823	0.0308

Test 1 Results

RUN		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gas Pressure		5	5	5	5	10	10	10	10	5	10	10	10	10	5	5	5
Inductive load		1	-1	-1	-1	-1	1	1	-1	-1	1	-1	-1	1	1	1	1
Intake Temp		80	90	80	80	90	80	90	80	90	90	80	90	80	90	80	90
Turbine Output		24	24	24	16	16	16	16	24	16	24	16	24	24	16	16	24
Efficiency		0.1901	0.1866	0.1871	0.1824	0.1825	0.1803	0.1779	0.1892	0.1753	0.1863	0.1815	0.1869	0.1897	0.1753	0.1783	0.1823
THD	Volts	0.0092	0.0094	0.0101	0.0102	0.0096	0.0089	0.0090	0.0099	0.0102	0.0089	0.0102	0.0102	0.0089	0.0093	0.0095	0.0088
	Amps	0.0268	0.0294	0.0310	0.0429	0.0422	0.0403	0.0386	0.0314	0.0464	0.0294	0.0458	0.0361	0.0293	0.0376	0.0404	0.0308

Test 2 Experimental Design

Order		Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Std	Run	Gas Pressure	Transformer (inductor)	Intake Temp	Turbine Output	Efficiency (fraction)	THD (current)
12	1	10.00	on	80.00	24.	0.197	0.0289
7	2	5.00	on	90.00	16.00	0.179	0.0423
9	3	5.00	off	80.00	24.00	0.1929	0.0321
5	4	5.00	off	90.00	16.00	0.1789	0.0439
2	5	10.00	off	80.00	16.00	0.1858	0.0414
1	6	5.00	off	80.00	16.00	0.1828	0.0403
16	7	10.00	on	90.00	24.00	0.1886	0.0301
6	8	10.00	off	90.00	16.00	0.1799	0.0409
10	9	10.00	off	80.00	24.00	0.194	0.0310
4	10	10.00	on	80.00	16.00	0.1846	0.0396
14	11	10.00	off	90.00	24.00	0.1845	0.0327
15	12	5.00	on	90.00	24.00	0.1808	0.0318
11	13	5.00	on	80.00	24.00	0.1911	0.0281
3	14	5.00	on	80.00	16.00	0.1799	0.0423
13	15	5.00	off	90.00	24.00	0.1837	0.0322
8	16	10.00	on	90.00	16.00	0.1819	0.0424

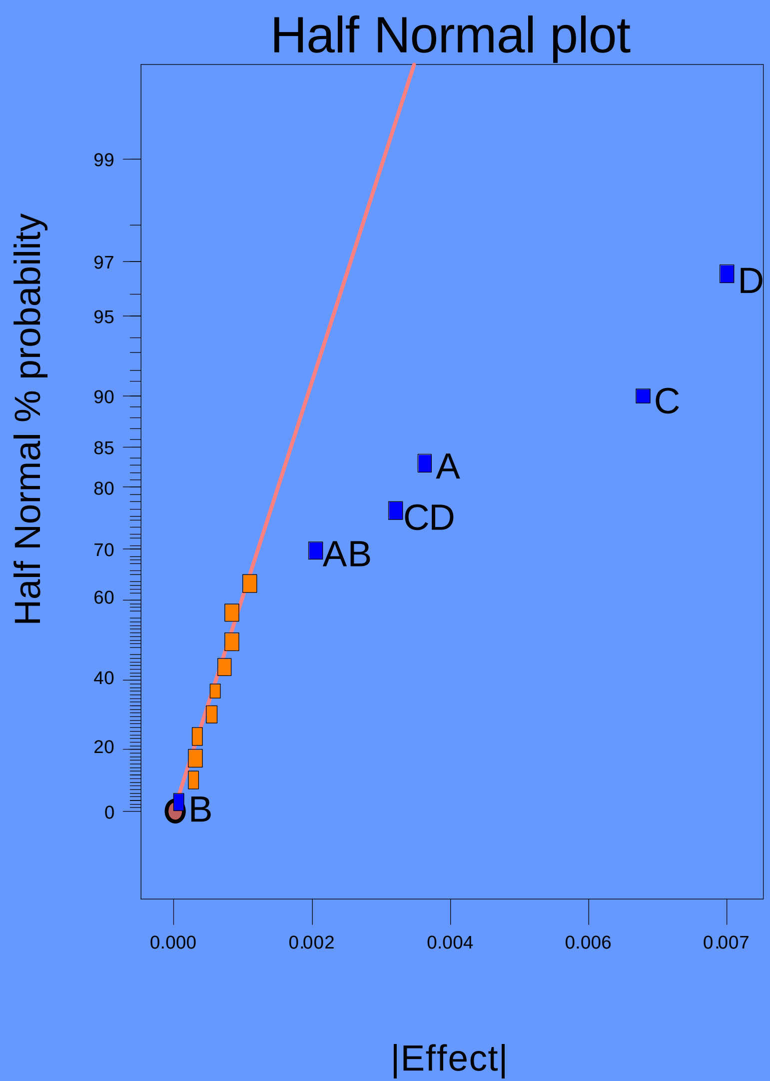
Test 2 Results

RUN		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gas Pressure		10	5	5	5	10	5	10	10	10	10	10	5	5	5	5	10
Inductive load		1	1	-1	-1	-1	-1	1	-1	-1	1	-1	1	1	1	-1	1
Intake Temp		80	90	80	90	80	80	90	90	80	80	90	90	80	80	90	90
Turbine Output		24	16	24	16	16	16	24	16	24	16	24	24	24	16	24	16
Efficiency		0.1970	0.1790	0.1929	0.1789	0.1858	0.1828	0.1886	0.1799	0.1940	0.1846	0.1845	0.1808	0.1911	0.1799	0.1837	0.1819
THD	Volts	0.0104	0.0109	0.0119	0.0118	0.0117	0.0117	0.0101	0.0110	0.0112	0.0102	0.0113	0.0106	0.0101	0.0109	0.0112	0.0108
	Amps	0.0289	0.0423	0.0321	0.0439	0.0414	0.0403	0.0301	0.0409	0.0310	0.0396	0.0327	0.0318	0.0281	0.0423	0.0322	0.0424

Test 2

DESIGN-EASE Plot
efficiency

A: Gas Pressure
B: Inductive Load
C: Intake Temp
D: Turbine Ouput

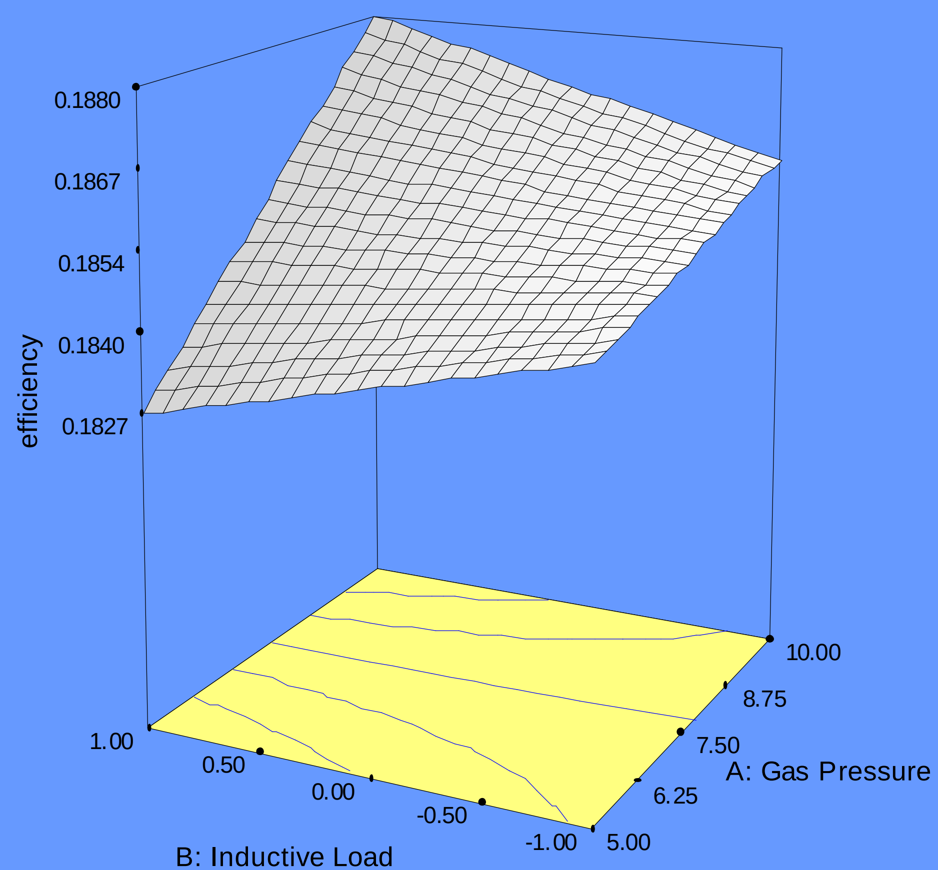


Test 2

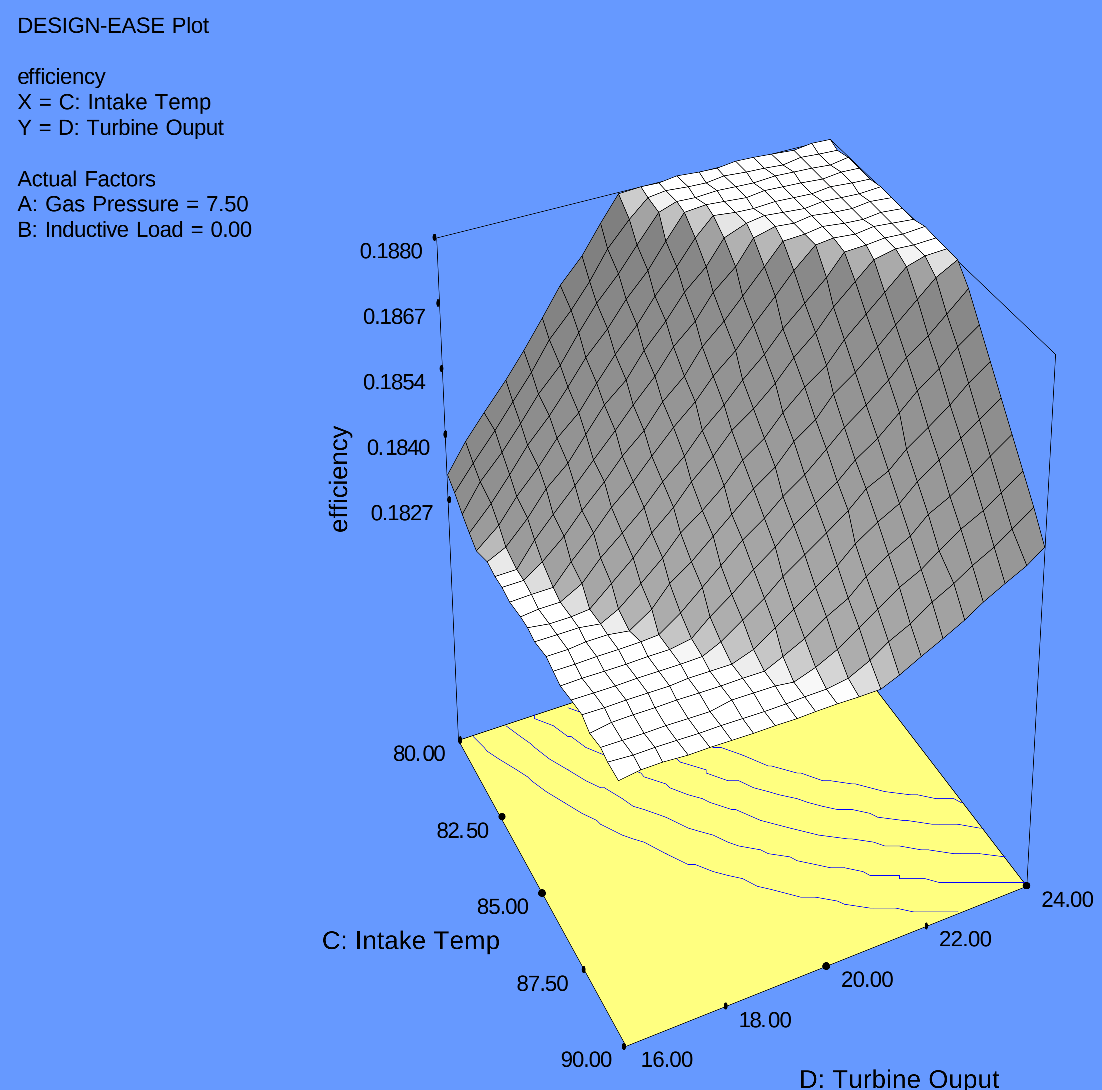
DESIGN-EASE Plot

efficiency
X = A: Gas Pressure
Y = B: Inductive Load

Actual Factors
C: Intake Temp = 85.00
D: Turbine Ouput = 20.00



Test 2


DESIGN-EASE Plot
efficiency
X = C: Intake Temp
Y = D: Turbine Ouput
Actual Factors
A: Gas Pressure = 7.50
B: Inductive Load = 0.00
0.1880
0.1867
0.1854
0.1840
0.1827
efficiency
80.00
82.50
85.00
87.50
90.00
C: Intake Temp
16.00
18.00
20.00
22.00
24.00
D: Turbine Ouput

Test 3 Experimental Design

Order Std	Run	Factor 1 Turb 1 output	Factor 2 Turb 2 output	Factor 3 Xfmr (ind)	Factor 4 Turb 1 Temp	Factor 5 Turb 2 Temp	Resp 1 Eff (fract)	Resp 2 Eff (fract)	Resp 3 THD 1 (current)	Resp 4 THD 2 (current)
32	1	24.00	24.00	on	90.00	90.00	0.18970	0.20022	0.03139	0.02083
11	2	16.00	24.00	off	90.00	80.00	0.18322	0.20424	0.0483	0.03094
15	3	16.00	24.00	on	90.00	80.00	0.18342	0.20462	0.04139	0.02672
18	4	24.00	16.00	off	80.00	90.00	0.19378	0.18754	0.03372	0.04478
26	5	24.00	16.00	off	90.00	90.00	0.19062	0.18874	0.03278	0.04300
16	6	24.00	24.00	on	90.00	80.00	0.19023	0.20316	0.03056	0.02683
6	7	24.00	16.00	on	80.00	80.00	0.19220	0.19137	0.03272	0.04261
2	8	24.00	16.00	off	80.00	80.00	0.19253	0.19300	0.03606	0.04439
21	9	16.00	16.00	on	80.00	90.00	0.18486	0.18960	0.04167	0.03922
3	10	16.00	24.00	off	80.00	80.00	0.18601	0.20304	0.04267	0.03656
5	11	16.00	16.00	on	80.00	80.00	0.18543	0.19161	0.04028	0.04178
13	12	16.00	16.00	on	90.00	80.00	0.18409	0.19355	0.04194	0.04178
9	13	16.00	16.00	off	90.00	80.00	0.18385	0.19369	0.04844	0.04872
31	14	16.00	24.00	on	90.00	90.00	0.18345	0.19982	0.04039	0.03139
19	15	16.00	24.00	off	80.00	90.00	0.18588	0.19966	0.04700	0.03656
12	16	24.00	24.00	off	90.00	80.00	0.19180	0.20353	0.04206	0.04006
4	17	24.00	24.00	off	80.00	80.00	0.19369	0.20337	0.04139	0.03911
28	18	24.00	24.00	off	90.00	90.00	0.19013	0.20019	0.03744	0.03489
1	19	16.00	16.00	off	80.00	80.00	0.18545	0.19232	0.04478	0.04467
17	20	16.00	16.00	off	80.00	90.00	0.18585	0.19062	0.04283	0.04394
23	21	16.00	24.00	on	80.00	90.00	0.18609	0.20017	0.04144	0.02883
24	22	24.00	24.00	on	80.00	90.00	0.19356	0.19939	0.03061	0.03150
30	23	24.00	16.00	on	90.00	90.00	0.18996	0.18648	0.03228	0.04283
22	24	24.00	16.00	on	80.00	90.00	0.19257	0.18722	0.03294	0.04072
25	25	16.00	16.00	off	90.00	90.00	0.18263	0.18749	0.04639	0.04778
29	26	16.00	16.00	on	90.00	90.00	0.18270	0.18965	0.04478	0.03900
27	27	16.00	24.00	off	90.00	90.00	0.18276	0.20064	0.04633	0.03683
14	28	24.00	16.00	on	90.00	80.00	0.18960	0.19296	0.03411	0.04328
20	29	24.00	24.00	off	80.00	90.00	0.19302	0.19968	0.03894	0.03833
8	30	24.00	24.00	on	80.00	80.00	0.19179	0.20351	0.03317	0.02833
7	31	16.00	24.00	on	80.00	80.00	0.18527	0.20319	0.04467	0.03039
10	32	24.00	16.00	off	90.00	80.00	0.19010	0.19342	0.04211	0.05033

Test 3 Results

	Output kW		Inductive	Intake Temp		Efficiency		THD #1		THD #2	
RUN	#1	#2	Load	#1	#2	#1	#2	Volts	Amps	Volts	Amps
1	24	24	1	90	90	18.970%	20.022%	1.000%	3.139%	0.900%	2.083%
2	16	24	-1	90	80	18.322%	20.424%	1.094%	4.783%	1.033%	3.094%
3	16	24	1	90	80	18.342%	20.462%	1.122%	4.139%	0.967%	2.672%
4	24	16	-1	80	90	19.378%	18.754%	1.128%	3.372%	1.089%	4.478%
5	24	16	-1	90	90	19.062%	18.874%	1.117%	3.278%	1.072%	4.300%
6	24	24	1	90	80	19.023%	20.316%	1.122%	3.056%	0.978%	2.683%
7	24	16	1	80	80	19.220%	19.137%	1.150%	3.272%	1.056%	4.261%
8	24	16	-1	80	80	19.253%	19.300%	1.122%	3.606%	1.117%	4.439%
9	16	16	1	80	90	18.486%	18.960%	1.217%	4.167%	1.094%	3.922%
10	16	24	-1	80	80	18.601%	20.304%	1.233%	4.267%	1.144%	3.656%
11	16	16	1	80	80	18.543%	19.161%	1.200%	4.028%	1.089%	4.178%
12	16	16	1	90	80	18.409%	19.355%	1.306%	4.194%	1.150%	4.178%
13	16	16	-1	90	80	18.385%	19.369%	1.250%	4.844%	1.200%	4.872%
14	16	24	1	90	90	18.345%	19.982%	1.261%	4.039%	1.100%	3.139%
15	16	24	-1	80	90	18.588%	19.966%	1.261%	4.700%	1.194%	3.656%
16	24	24	-1	90	80	19.180%	20.353%	1.283%	4.206%	1.211%	4.006%
17	24	24	-1	80	80	19.369%	20.337%	1.300%	4.139%	1.211%	3.911%
18	24	24	-1	90	90	19.013%	20.019%	1.156%	3.744%	1.122%	3.489%
19	16	16	-1	80	80	18.545%	19.232%	1.261%	4.478%	1.222%	4.467%
20	16	16	-1	80	90	18.585%	19.062%	1.256%	4.283%	1.156%	4.394%
21	16	24	1	80	90	18.609%	20.017%	1.244%	4.144%	1.094%	2.883%
22	24	24	1	80	90	19.356%	19.939%	1.256%	3.061%	1.150%	3.150%
23	24	16	1	90	90	18.996%	18.648%	1.311%	3.228%	1.172%	4.283%
24	24	16	1	80	90	19.257%	18.722%	1.206%	3.294%	1.106%	4.072%
25	16	16	-1	90	90	18.263%	18.749%	1.322%	4.639%	1.267%	4.778%
26	16	16	1	90	90	18.270%	18.965%	1.350%	4.478%	1.117%	3.900%
27	16	24	-1	90	90	18.276%	20.064%	1.228%	4.633%	1.156%	3.683%
28	24	16	1	90	80	18.960%	19.296%	1.250%	3.411%	1.111%	4.328%
29	24	24	-1	80	90	19.302%	19.968%	1.211%	3.894%	1.206%	3.833%
30	24	24	1	80	80	19.179%	20.351%	1.250%	3.317%	1.117%	2.833%
31	16	24	1	80	80	18.527%	20.319%	1.289%	4.467%	1.106%	3.039%
32	24	16	-1	90	80	19.010%	19.342%	1.289%	4.211%	1.256%	5.033%

Test System 2

GASEOUS EMISSIONS TEST RESULTS SUMMARY
NiSource
Aetna Complex
Gary, Indiana
Micro Turbine

Test No.	Date	Time	Load KW	Flow dscfm	NO_x ppmvd	CO ppmvd	THC ppmv as C_3H_8	O_2 %	CO_2 %	NO_x at 15% O_2	CO at 15% O_2	NO_x lbs/hr	CO lbs/hr	B_{ws}	THC lbs/hr as C_3H_8
1	09/07/01	0857-0957	28	460.1	1.0	36.2	4.3	18.56	1.49	2.52	91.23	0.003	0.073	0.078	0.015
2	09/07/01	1018-1118	28	461.7	0.9	32.2	3.9	18.36	1.48	2.09	74.73	0.003	0.065	0.077	0.013
3	09/07/01	1143-1243	28	467.7	0.9	28.9	3.1	18.38	1.47	2.11	67.65	0.003	0.059	0.077	0.011
Average				463.2	0.9	32.4	3.8	18.43	1.48	2.24	77.87	0.003	0.066	0.077	0.013

Test System 2
Vibration Measurements
Position on Frame